A model for implementing an automated change management process for construction megaprojects

by

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AUTHOR'S DECLARATION

I hereby declare that I, Shahin Karimidorabati, am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

This thesis develops a model for implementing and continuously improving the automated change management process for construction megaprojects. Changes are inevitable in megaprojects. Their negative impact along with the necessity of the circulation of numerous change documents, such as; Request For Information (RFIs), Change Request (CRs), and Project Change Notice (PCNs) in real time and to the right person have required the stakeholders of mega-projects, especially project owners, to implement innovative change management systems. As well, in the industrial sector, the dominance of the "fast track" approach necessitates advanced change management that is based on formal process-based approaches using advanced Information Technology (IT). Thus, an automated workflow-based process with continuous improvement is required to effectively manage changes in construction megaprojects. Most current change management methods still rely on human discipline to follow blurred processes with repetitive tasks, which often break down due to human nature. However, automated change management is in its infancy. Thus, behaviour of and design principles for automated workflow-based change management processes are construction knowledge gaps based on which two main objectives are defined in this research.

The first objective seeks to identify the levels of change management processes in the construction industry and then to evaluate and quantify the performance difference between these levels. This thesis, thus, introduces a model of three levels, or "generations", of change management as an effective approach to understanding how change management can be continuously improved. The second objective seeks to develop and validate a model for continuous improvement of the third level "Generation Three" workflow-based process of change management as measured by improved compliance, reduction of workflow duration, better traceability, and achievement of desirable durations of workflow steady state. This "Generation Three" approach is assumed to be part of an

Electronic Product and Process Management System (EPPMS), a tool supporting execution of megaprojects.

To meet the aforesaid objectives, the research methodology uses a Discrete-Event Simulation (DES) model developed based on a change management process implemented in a Canadian oil and gas megaproject. Mechanistic arguments and the results of the validated simulation model of change management, which was executed for the three identified generations led to the conclusions that the "Generation Three" approach should result in:

a. better traceability of change documents throughout the automated workflow-based process due to the recordibility of date, time, and current status of the change documents in each task,
b. better process compliance due to the elimination of rework in repetitive tasks prompted by the automated workflow engine,
c. reduction of the duration of the change management workflow considering the limitations of IT for reducing the duration of professional work.

This research has thus led to a better understanding of the potential of automated management systems for improving processes such as change management in terms of traceability, compliance, and duration, but also of the limitations of such systems such as their ineffectiveness in substantially expediting professional practices that require off-line analysis, communication, negotiation and judgment.

Acknowledgements

First and foremost, I am so thankful to the Almighty without my true belief in whom, ending this PhD journey was not possible. Leaving the lovely divinity alone (as he always wanted to be!) and coming down to the terrestrial, the very first person to whom I am expressing my greatest gratitude is my research supervisor, Professor Carl T. Haas. A distinguished supervisor whose academic advice illuminated the path of my PhD and a true human being who always reached out his helping hand to me.

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I would also like to thank all my friends and colleagues for their valuable friendship and sharing their happy moments with me. Last but not the least I am deeply indebted to my parents, my older brothers, and my younger sister for their encouragement and spiritual support along with their commitment to looking after my ailing father far exceeded the call for duty and brought me peace of mind while I was busy with my studies.

Dedication

I dedicate this thesis to three people:

My dearest mother,

My lovely father,

and the one who was my role model .

Abbreviations

ACD: Activity Cycle Diagram

AIF: Activity-based Information Flow

BIM: Building Information Modeling

BPMN: Business Process Model and Notation

CII: Construction Industry Institute

CII-RT: Construction Industry Institute-Research Team

CIPP: Continuous Improvement Process Program

CO: Change Order

CPM: Critical Path Method

CR: Change Request

CSF: Critical Success Factor

DBF: Design-Build-Finance

DBFM: Design-Build-Finance-Maintain

DBFMO: Design-Build-Finance-Maintain- Operate

DBM: Design Basis Memorandum

DSM: Dependency System Matrix

DES: Discrete Event Simulation

EP: Engineering Procurement

EPC: Engineering Procurement Construction (Engineer-Procure-Construct)

EPPMS: Electronic Product and Process Management System

FEP: Front End Planning

FIDIC: Fédération Internationale Des Ingénieurs-Conseils/International Federation of Consulting Engineers

IT: Information Technology

ICE: Institution of Civil Engineers

IKIS: Interactive Knowledge-Intensive System

MOC: Management Of Change

NAIF: Non-Activity Information Flow

PCMS: Project Controls and Management Systems

PCN: Project Change Notice

PEP: Project Execution Plan

PMT: Project Management Team

PO: Purchase Orders

RFI: Request/Return For Information

WBS: Work Breakdown Structure

Wf: Workflow

Wf Imp: Workflow Implementations

Wf Inst: Workflow Instances

Wf Temp: Workflow Template

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Chapter 1
Introduction

1.1 Background and Motivation

Changes in construction projects, due to their impact on the process of the project and thus its performance, are one of the most important aspects of the construction industry. Modern change theory and philosophy posit that change is inevitable, while supporting the concept that change can be controlled and to some extent avoided. Changes constitute a major cause of delay, disruption, cost increases, poor quality and unsatisfying performance. They are also known as a main factor of litigation between the owners and constructors. Hence, effective change management by which all potential elements of changes are considered and proactive actions taken has always been in the interest of stakeholders of the construction industry. To meet this need many methods and techniques; such as an integrated system for change management (Motawa et al, 2007) or a prediction system for change management (Zhao et al, 2010) have been developed.

While BIM (Building Information Modelling) advocates would claim that projects are data centric, it can be argued that construction projects are essentially process-based, and with the advent of Information Technology (IT) and its critical role in this industry, projects, especially megaprojects, are being managed remotely through the involvement of many contractors, designers, vendors and project managers, all linked via the Internet. The volume of data and documents, such as Requests For Information (RFIs), Change Requests (CRs), Project Change Notices (PCNs), being transferred and exchanged amongst these stakeholders, especially when changes happen, is considerable. For these reasons and because of the paramount importance of management of changes, automated workflow-based change management processes have been implemented to reduce the time and cost of the data exchange.

Automated processes are promising to bring management of change to a new level. These automated processes are implemented via "workflows" as a part of an EPPMS (*Electronic Product and Process Management System).* An EPPMS facilitates the execution of megaprojects by linking project stakeholders over a range of distances via the internet and system servers, formalizing and automating work processes, and automating the document management system. Needs still exist however to formalize automated change management processes to identify effective change management process aspects and workflows, to characterize their performance, and to examine the hypothesis that workflow-based change management results in better performance than other change management systems for megaprojects. Behavior of and design principles for automated change management processes are construction knowledge gaps, since conventional methods (paper-based) or electronic (emails and the Internet) methods still rely on human discipline to follow specified processes, which often break down because of human nature. In this respect, the hypothesis of this dissertation is that an automated workflow-based process, based on the provisional objectives (defined below), can improve the change management process and will have significant benefits in comparison to less or non-automated processes currently being used in the construction industry.

1.2 Research Objectives

Based on the preceding discussion, this research seeks to design and implement a model based on an automated workflow-based change management system that is robust and has performance characteristics that result in achieving the following objectives:

- Evaluate and quantify the difference between levels of automation of change management processes.
- Develop and validate a model for continuous improvement of automated change management processes as per defined metrics.

Sub-objectives of the preceding objectives that are related to direct savings should include:

- Improve the communication efficiency during a change order process.
- Facilitate identification of unnecessary communication points during the change order process.
- Facilitate identification of bottlenecks and critical points in the data transfer process.
- Reduce change cycle time leading to reduction of project duration.

Sub-objectives of the preceding objectives that are related to indirect savings should include:

- Reduce cost of changes.
- Improve quality and productivity.
- Support compliance for litigation; reduced risk of litigation; and reduced cost of "discovery", if litigation is pursued.
- Improve the probability of use of alternative dispute resolution.

1.3 Research Scope

The automated workflow-based change management process modeled is assumed to be part of an Electronic Product and Process Management System (EPPMS), a tool for the execution of megaprojects. In addition to the automated workflow-based change management process, a typical EPPMS may include "supply nexus management", "interface management and risk management", "knowledge management" (Figure 1-1).

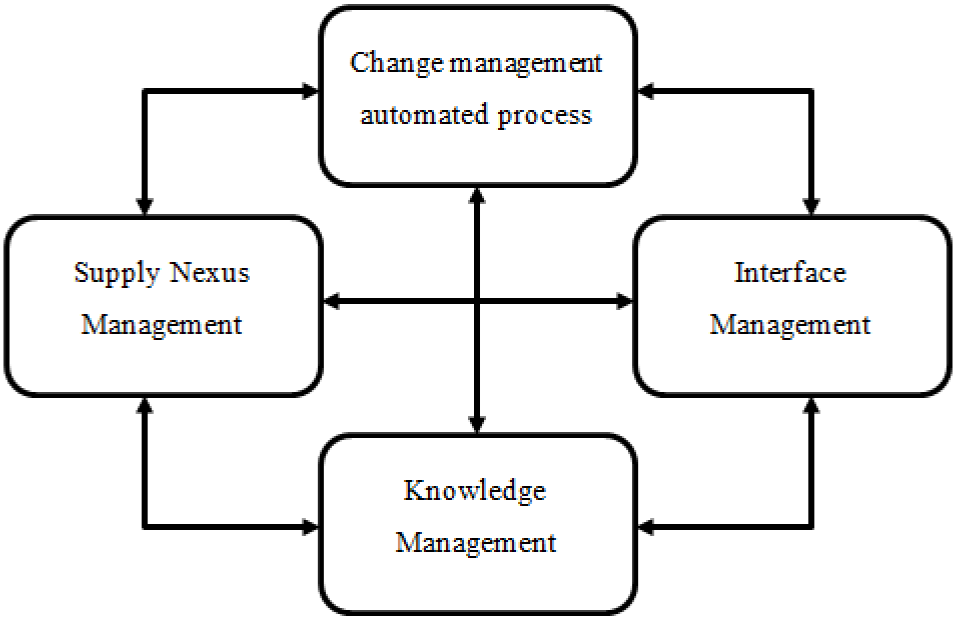


Figure 1-1: Four aspects of a typical EPPMS

An EPPMS can be utilized in megaprojects such as oil and gas, power plants, and refineries. Typically several major contractors, Engineering Procurement Construction (EPCs), and many subcontractors work on these projects, and therefore, a high level of engineering and collaboration along with sophisticated project management is required. In the following Chapter, a clear definition of a typical construction megaproject and its characteristics is explained.

This research makes extensive use of data from a Canadian oil and gas megaproject, budgeted at approximately $1.2 billion USD. The aforesaid project includes over 800 change requests issued and evaluated in a combined paper-based and electronic process and an automated process during the execution of the project's construction phase. Appendices (A) and (B) include a snapshot of a spreadsheet showing a sample of data extracted from the database and change logs of the project.

Since the change management process spans the project life cycle from the front end planning (FEP) phase to the operations phase (Figure 1-2), the workflow-based change management process can cover this spectrum as well. However, this research evaluates and quantifies the levels of change management process used in the procurement and construction phases of a Canadian oil and gas megaproject, considered as a case study, according to defined metrics, explained in Chapter three.

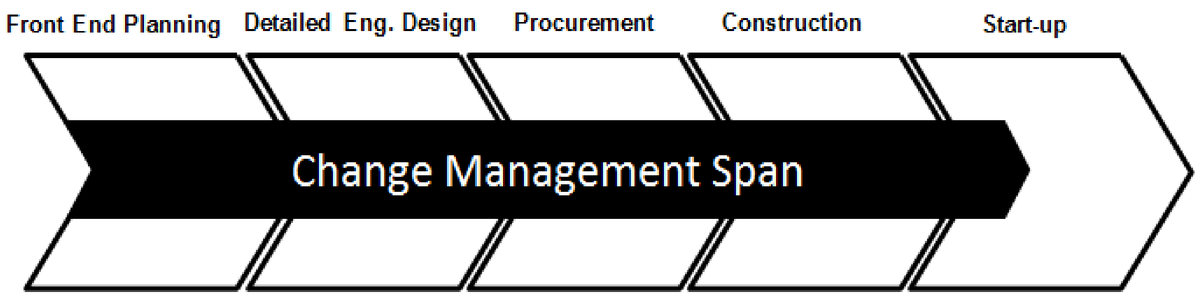


Figure 1-2: Change management span in Project Life Cycle (CII-1994)

1.4 Research Methodology

To meet the objectives defined in Section 1.2, the following research methodology was adopted:

- **Preliminary Stage:** as shown in Figure 1-3, the problem statement and literature review are correlated. In the problem statement, the existing needs to conclude the research idea, main objectives, and scope of the research were identified. In line with the problem statement, a comprehensive literature review; journal papers, books, magazines, and the websites relevant to change and change management processes in the scope of construction megaprojects was conducted. The continuity of the literature review was maintained throughout this research.

- **Case Study and Data Collection:** to meet the research objectives, the empirical data of a Canadian oil and gas megaproject, considered as a case study, was analyzed. The data analysis was broken down into two phases; the analysis of the database and change logs where the proper data (time stamps, role and responsibilities, and current status) of change requests existing in different change management processes of the aforesaid project was recorded and the simulation of the change request process implemented in the above project. These two phases were conducted in parallel. Face to face interviews and conference calls were conducted where the complexity of the data analysis or the change request process led to ambiguity.

- **Verification, Validation, and Evaluation:** the results of data analysis, mainly as 'wait time' and 'nominal working time' were the input data for the simulation model developed as per the project's change request process (explained in Chapters four and five). In order to realistically simulate the change request process of the project, the simulation model was modified repeatedly and the database and change logs were reanalyzed accordingly. To meet the first objective of the research, the validated simulation model of the change request process was utilized in three different scenarios defined for three levels of change request processes respectively in order to test and evaluate the simulation model behavior based on these scenarios. The first scenario was related to the paper-based or "Generation One" change request process where hardcopy documentation and physical change files circulation amongst project stakeholders through faxes and snail mails exist. The second scenario was concerned with the electronic or "Generation Two" change request process where softcopy documentation (electronic folders and spreadsheets) and scanned PDF format change files circulation amongst stakeholders through the Internet and emails exist. The third scenario pertained to the automated workflow-based or "Generation Three" change request process where the circulation of customized electronic change request forms with pre populated fields amongst the authorized project stakeholders through Database Management System, Document Management System, and workflow engine exists. To meet the second objective, the data of eight different change request workflow implementations (see Section 3.3.4 in Chapter three) in the project was analyzed and the results were compared together based on time and compliance as the defined metrics.

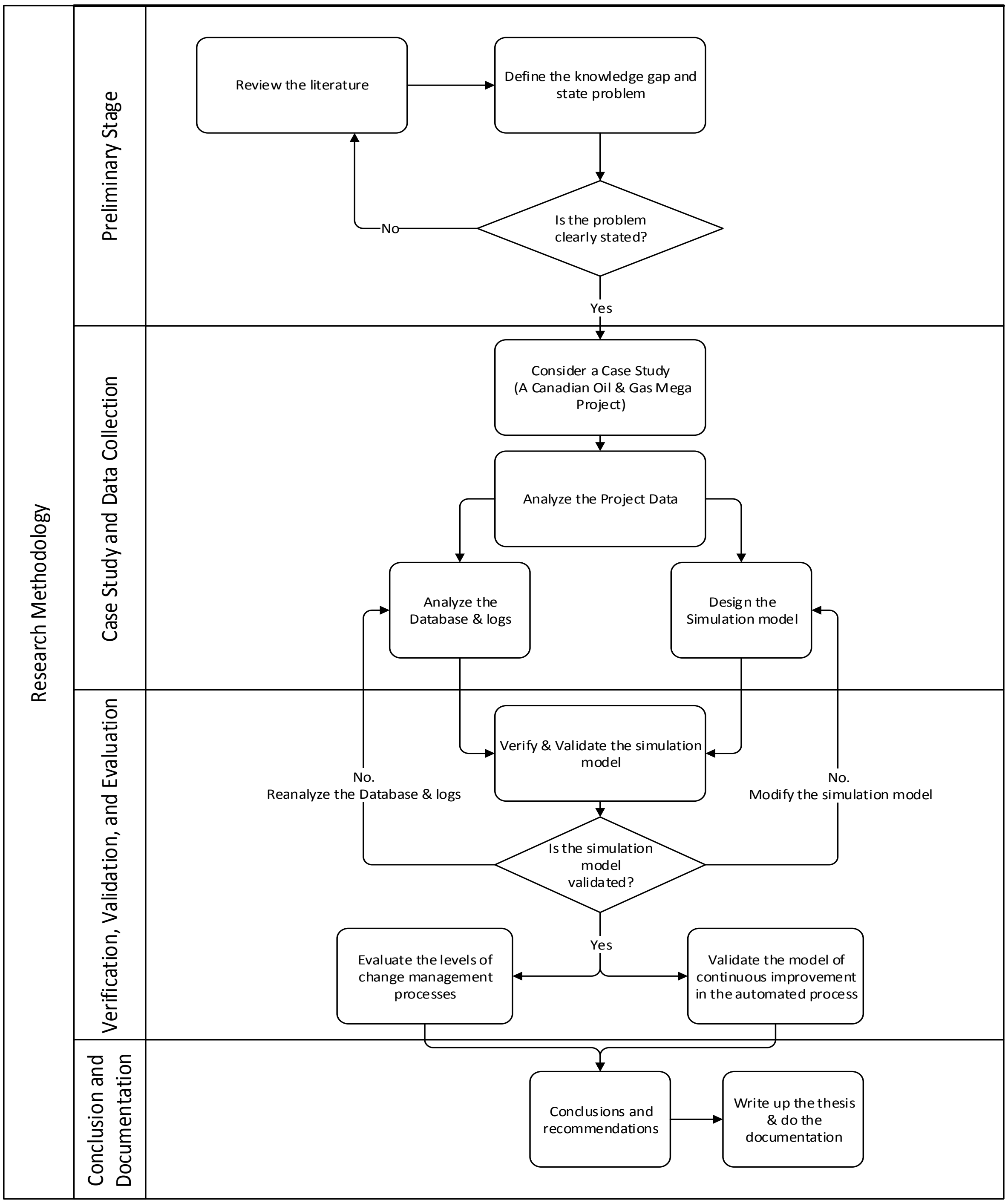


Figure 1-3: Research Methodology Diagram

- **Conclusion and Documentation:** the last stage of the methodology focused on conclusion and documentation. It included the results of the previous stage along with the reiteration of the sub objectives and a summary of which one of these sub objectives is met in this research. In addition, some insights that can be followed as the further research were suggested.

1.5 Thesis Structure

The structure of this thesis is broken down into seven Chapters. The Introduction is Chapter one where the background and motivation in addition to research objectives, research scope, and research methodology are explained. Chapter two covers the literature review of the most recent and important papers with the topics of change and change management in the construction industry along with commercial software and services relevant to the proposal theme and their analysis. It demonstrates how far the academia and the construction industry have furthered the process of change management and what remaining knowledge gaps exist. Chapter three includes the proposed methodology to fulfill the research objectives. An automated workflow-based process, developed by Coreworx™ and studied by the author of this thesis, is introduced in order to be compared with existing alternatives. The proposed methodology is the backbone of this comparison to reveal how effective the automated workflow-based process promises to be in terms of time and cost reduction as well as quality improvement when it comes to change management and the related data and document management process. Chapter four discusses the data collection, the challenges of data collection due to the change management processes' complex behavior, and the development of a simulation model for the automated workflow-based change management process in Simul8™, the selected simulation software package. Chapter five contains the verification and validation of the detailed simulation model for automated workflow-based change management process. Chapter six explains the execution and the output analysis of three simplified simulation models developed based on three scenarios defined for the three levels of change management processes. It also includes the analysis of the continuous improvement process program for the automated workflow-based change management process as per the defined metrics. Finally, Chapter seven highlights the results of this research and also the potential ideas to be considered for further research.

Chapter 2
Literature Review

This Chapter includes the general definition of change and other terms relevant to change, process, and workflow. Different levels of change management are discussed in detail along with industry approaches and academic papers toward managing changes. Terms and definitions vary between industry sectors and regions of the world. These variations are identified where appropriate. The role of Discrete-Event Simulation (DES) in construction engineering and management is also described.

2.1 Megaprojects in the Construction Industry

Since this research and EPPMS target megaprojects of the construction industry, a comprehensive definition of "megaproject" helps the reader better understand the scope of the research. Zhai et al, (2009) state that a megaproject is always defined in terms of such variables as the scale of investment, the number of project staff, the social impact of the project, and the complexity of the project. Given these variables, the Federal highway administration of the United States (2007 cited in Zhai et al 2009) defines a megaproject as a major infrastructure project with the value of more than $500 million that attracts a high level of public attention and national interest due to its substantial impacts on the community, environment, and national budgets. Fiori and Kovaka (2005) also state that other characteristics in addition to project cost must be considered to define megaprojects thus, they characterize megaprojects by *magnified budget, extreme complexity, increased risk, lofty ideals, and high visibility, in a unified form that represents a significant challenge to stakeholders, a significant impact on the community, and pushes the limits of the construction experience.*

Contractually, megaprojects are often defined as Public Private Partnership (PPP) (Van Marrewijk et al, 2008) implemented through various contract agreements such as Design-Build-Finance (DBF), Design-Build-Finance-Maintain (DBFM) or Design-Build-Finance-Maintain-Operate (DBFMO). Clients with large, complex industrial projects such as process-plant or power-plant projects may select Engineering Procurement Construction (EPC) method. Under an EPC (also called Engineer-Procure-Construct) arrangement, the concessionaire (the employer) provides the finance and is not expected to be involved in the day-to-day progress. In return for a fixed price, the contractor is totally responsible to design the installation, provide the materials, and construct the infrastructure (Potts & Ankrah, 2014). Different forms of contracts may lead to different change processes. An effective change management system can be designed by understanding the change orders process or workflow, which can be compiled from the standard form of contract (Figure 2-1).

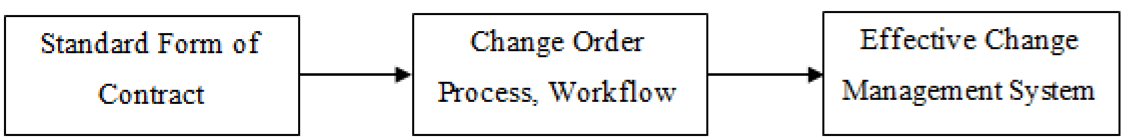


Figure 2-1: Relation between effective change management, process, and contract

Although different types of contracts may lead to different processes for managing changes in project, this research addresses those megaprojects awarded as EPC (Engineering, Procurement, Construction) outlined above.

Each megaproject involves a variety of stakeholders participating in the different phases of the project life cycle. There are internal participants, including the engineers, document controllers, project managers and other members of the project team in the office. There are also the construction personnel and external suppliers on the construction sites. There are legal people who need to look into contractual documents and claims, especially when changes occur and the project goes awry. To orchestrate this and run as smoothly a project as possible, an automated workflow-based change management process, named "Generation Three" in this thesis and explained later, along with these other aspects mentioned above is emerging as a core tool. Figure (2-2) illustrates a typical megaproject and its stakeholders' connections.

To develop a change management workflow-based process, it is essential to understand changes and change management in the construction industry. The next Sections provide an overview of these concepts.

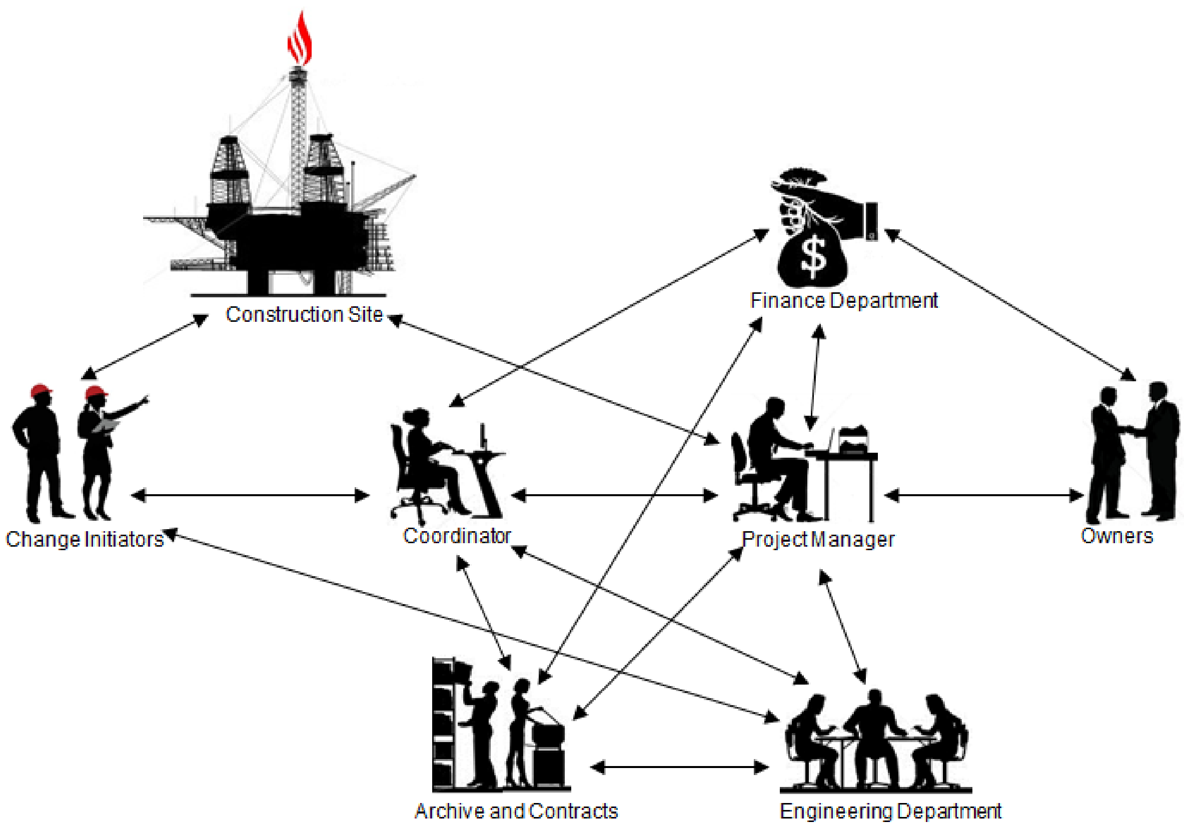


Figure 2-2: Typical megaproject stakeholders' connections

2.2 What is Change and Change Management in the Construction Industry?

2.2.1 Definition of Change

Changes are common and inevitable in construction projects and can occur from different sources, by various causes, at any phases or stages of a project (Motawa et al. 2007). By definition “change” is related to any form of additions, deletions, or revisions within the general scope or goals defined in a project contract and that causes an adjustment to both price and time of contract (CII Project Change Management Research Team Nov 1994;Ibbs, Wong & Kwak 2001; Ibbs et al. 2003). Since they present a variety of challenges for almost every party and stakeholder involved in a construction project, changes have indisputable impacts on the project performance; such as labor efficiency (Hanna, Russell & Vandenberg 1999), thus changes influence the quality as well. The construction industry exhibits this behavior as projects rarely progress precisely as anticipated. In other words, the occurrence of change is inevitable, hence changes must be acknowledged, systematically managed, and not be ignored (Lee, Peña-Mora & Park 2005). A better understanding of causes of change will lead to better management of change.

2.2.2 Common Causes of Change

Changes are driven by different factors categorized as *external factors* and *internal factors* (Walker 2007). The former, as Walker (2007) states, mainly includes some uncertainties, such as; government related uncertainties, economic sanctions, social, legal, technological uncertainties, natural calamities, and unexpected site conditions all related to the *external environment* of construction projects where the owners, engineers, contractors or other stakeholders have the least control on the aforesaid factors. The latter, internal factors mainly include project size, scope, quality, schedule, cost, contract/procurement changes, drawing errors, design changes, design errors, design coordination, quality inspection, rework, safety incident report, and value engineering happening within the *internal environment* of the project where the stakeholders possess comprehensive control on the above factors (Walker, 2007). In the construction industry, the internal and external environments are interconnected together, and the former is mainly under the influence of the latter. Thus the external factors of change could have a negative or positive impact on the internal ones.

2.2.3 Change Order (CO)

Anastasopoulos et al (2010) define change orders as formal contractual documents issued to accommodate the additional work in a contract. These additional works, according to the research by Alnuaimi et al (2010), are concerned with project scope variation, design errors, material quantities, and unit rate changes. The American Institute of Architects (Article 121.1 of AIA A201, 1977) defines a change order as:

> " *a written order to the contractor signed by the owner and architect, issued after execution of the contract, authorizing a change in the work or an adjustment in the contract sum or contract time"*

In almost every construction project the occurrence of change orders is very common and inevitable and often results in an increase of 5% to 10% in the contract price (Serag et al. 2010). In other words, as the recent research of Anastasopoulos et al (2010) on highway construction/maintenance indicates, the completion of a project within the original scope of work is hard to achieve. Timely review and approval of change orders can empower the team to react quickly to mitigate the consequences of the change (Aibinu, 2008). Further, Aibinu states that the expedient review and dispatch of change orders may prevent them from becoming claims during the closeout of the project. The author of this thesis argues that an automated workflow-based process will be a contributing factor to the timely review and approval or rejection of change orders, since it minimizes, if not eliminates, the delay time that exists in dispatching the change orders. It is commonly accepted that it is cheaper to resolve conflicts within the day-to-day onsite contract administration mechanism rather than referring them to a third party for resolution.

If not timely predicted or proactively controlled, change orders, along with their impact on the project cost and duration, can have a negative impact on construction productivity (Moselhi, Assem & El-Rayes 2005). Hence, it is important, especially in the pre-award phase of project management, to comprehend the factors associated with change orders since such an understanding contributes to minimize the concomitant contractual aberrations (Anastasopoulos et al. 2010). Charoenngam et al (2003) state that a change order has these main characteristics:

a) Authorization of a requested change is in the form of a written document,

b) No fault from the contractor side brings about the change,

c) Changed work is an appendage to the original contract and hence causes extra cost for the contract price.

What is missing in the system hypothesized by Charoenngam et al (2003) is an automated workflow-based process to increase the compliance and accuracy in the process of evaluating the change orders, filling the forms and attachments, and circulating them in a timely manner. This is one of the knowledge gaps addressed by the research presented in this thesis.

2.2.4 Change Request (CR)

Keller (2005) states that change requests are declarative documents of what is to be accomplished. Moghaddam (2012) defines change requests as a form of document issued by a contractor due to some unforeseen factors. Depending on for which discipline it is used, change requests may have different terms. After studying the documents of a Canadian Oil and Gas project, selected as a case study in this thesis, the author of this thesis refers to four types of change requests; Engineering, Vendor, Contract, and Field. These change requests are defined as follows:

2.2.4.1 Engineering change request (ECR)

This is a formal document to initiate review for authorization of any change requested by engineering contractors. This is considered as an input to the contracts department to execute the change order for the revised contract price as a result of the change.

2.2.4.2 Vendor change request (VCR)

As a formal document, this type of change request initiates review for vendors' authorization of any change in scope, cost and/or schedule for work awarded to vendors for supply of packages, bulk materials, and other items (miscellaneous items) against Purchase Orders (PO). It is also considered as an input to the EP (Engineering Procurement) department to coordinate issuance of a revised Purchase Order (PO) with the project owner's procurement department.

2.2.4.3 Field change request (FCR):

This is a formal document to initiate review for field contractors' authorization of any change in scope, cost and/or schedule in module fabrication or field construction during the construction phase of the project. This is considered as an input to the contracts department to execute change order for the revised contract price as a result of the change.

2.2.4.4 Contract Change Request (CCR):

As a formal document, this type of change request initiates review for authorization of any addition or deletion in the scope of work which results in change in cost and/or schedule of project.

Appendix (C) includes a format for a change request form.

2.2.5 Project Change Notice (PCN)

According to document analysis of a Canadian Oil and Gas project, selected as a case study in this thesis, a Project Change Notice (PCN) is a standardized form used to document the source, description and resolution of proposed changes to an established Design Basis Memorandum (DBM) and/or Project Execution Plans (PEP). As the last stage in a typical change management process, the PCN serves to complete the process of the Management Of Change (MOC) for recording, information distribution, implementation, and close-out of the change. A standard PCN is provided in Appendix (D).

2.2.6 Request for Information (RFI)

According to document analysis of a Canadian Oil and Gas project, selected as a case study in this thesis, an RFI, as a standard documented format is used to collect written information concerned with a design clarification, confirmation of the interpretation of drawing details, supplemental instructions from either the project management team (PMT) or any company engaged in the project process. The discovery or perception of a conflict, ambiguity, or error within technical documents can be other reasons to issue an RFI by the affected party. An RFI can be used to call the owner's attention should the affected party, such as a contractor or subcontractor, due to inferiority of a product, offer an alternate proposal to perform the work within the budget. RFIs can be precursors of change requests. A standard RFI form is included in Appendix (E).

2.2.7 Non-Conformance Report (NCR)

A nonconformance report is a standard document filled by the project contractor usually during the construction process to explain what has gone wrong and is being reported as nonconformity and what has been the cause of the nonconformity.

2.2.8 Definition of Change Management

In the construction environment, where changes can be expected and even anticipated, comprehensive methodologies and good management systems to effectively manage changes and administrate contracts become important (Nalewaik, 2012). Kumar (Kumar 2000 cited in Nalewaik 2012, p:2) states that "*change management is a function of project controls*" and defines change management system as "*a collection of formal, documented procedures that define the steps by which change decisions are made and how official project documents must be managed*". Implemented as both a written process and an electronic database, a change management methodology is intended to provide decision makers with the information and controls, required to manage change and take corrective actions in order to keep the project on track (Nalewaik, 2012).

The proper implementation of a change management system, as Nalewaik (2012) argues, may lead to documenting progress, improving record keeping, determining the causes of change, increasing early visibility of changes, establishing a cost, contingency, and schedule baseline, capturing the lesson learned, improving traceability of the documents related to changes, providing a consistent methodology for change order review, reducing human mistakes and rework in the change order process, and creating a foundation for claims management. Change, contingency, and claims are correlated together, hence as explained in the next Section a comprehensive approach in the management of change results in better contingency and claim management.

The document analysis of a Canadian Oil and Gas project, selected as the case study in this thesis, indicates that the *management of change (MOC) plan* is a document defining the specific work processes, tools and required procedures for managing changes during project execution from inception to completion. The MOC plan consists of inputs, tools, and outputs (Fig 2-3).

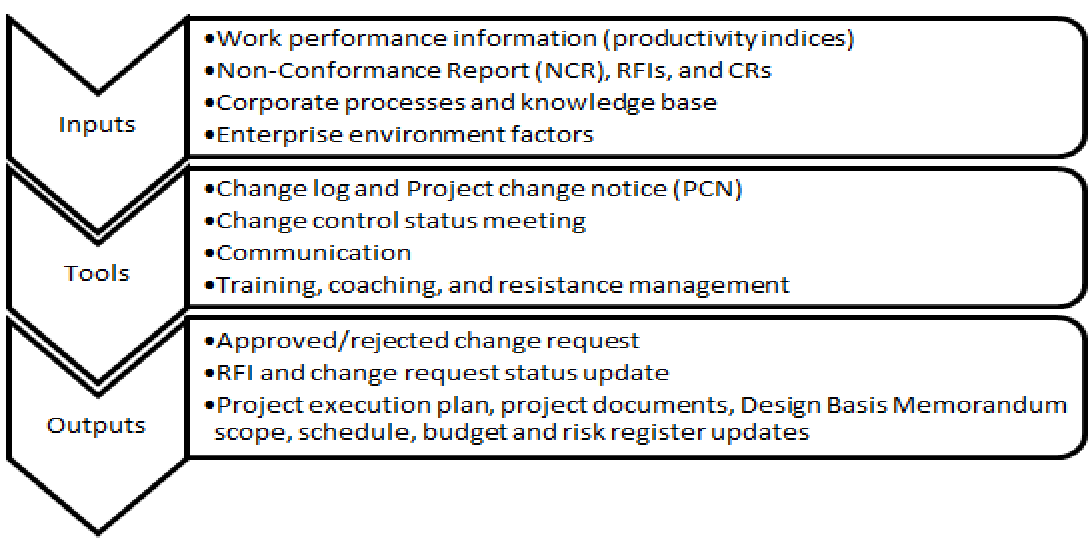


Figure 2-3: The inputs, tools, and outputs in a Management Of Change (MOC) plan

The details of the inputs, tools, and outputs may change in the procedures of the management of change for engineering, vendor, field, and contract respectively. An MOC plan includes RFIs, CRs and PCN each of which has their own process and procedure. In Chapter three the relation between RFIs, CRs, and PCN is explained.

2.2.9 Managing of Changes, Claims, and Contingency

Occurring frequently in the construction industry, a "claim" can be defined as the seeking of consideration (i.e.: payment or reward in a contractual agreement (Oxford Dictionary)) or change by one of the parties involved in the construction process (Arditi & Patel, 1989). The concept of a "claim" raises an adversarial inference in the minds of those to whom the claim has been addressed (Lane, 2009). Arditi & Patel (1989) introduce differing site conditions, delays, change orders, and inspection problems as the main causes of claims which may result in a change order or a modification. It may also lead to a negotiation between the parties. Therefore, changes and claims are interrelated and if not systematically managed, project changes lead to claims which in turn could give rise to litigation and discovery (Discovery: Compulsory disclosure of files and documents related to a judiciary case (Oxford Dictionary)). Once the change has been ordered, proper documentation to support the claim relevant to that change should be provided. Change orders should also be reviewed in detail and compared to an independent estimate of the cost/schedule impact. Change orders should be incorporated into the contract, and in order to do this, two methods exist. The first method is to create a line item in the project work breakdown structure for the change order. The second approach requires that the approved change order be broken down into its Work Breakdown Structure (WBS) elements, with those elements added back into the project WBS.

Shotwell and Schmitz (1993) define of contingency as "*a cost element added to the base budget to achieve an acceptable level of confidence, taking into assessment risk factors, in completing approved scope within schedule constraints and therefore meeting the prime objective*" (Shotwell and

Schmitz, 1993 cited in Nalewaik, 2012). Since changes affect the project budget, it is logical to think that change orders, as the documents of change, are related to the contingencies defined for the project. Nalewaik (2012) contends that like change management and claim management, contingency management is a process and its establishment in construction project controls management is a must. Considering the aforesaid points, the author of this thesis argues that an automated sub process for contingency management could be established under the automated workflow-based process of change management by which a more accurate control of budget and cost could be achieved. This argument is also mentioned as the research recommendation in the last Chapter.

2.3 Relevance of the Process-Based Approach in the Construction Industry

The fragmented nature of the construction industry, the lack of co-ordination and communication between parties, the informal and unstructured learning process, adversarial contractual relationships, and the lack of customer focus have been claimed to be what inhibit the industry's performance (Latham 1994, Egan 1998). To overcome these drawbacks, Latham (1994) suggests the use of *manufacturing* as a reference point, and Egan (1998) recommends *process modeling* as a method of improvement. Although some construction practitioners are adamant that, due to the unique nature of the construction industry, the transference and implementation of manufacturing into construction cannot be wholeheartedly adopted, many academics and practitioners, believing the construction industry has much to learn from manufacturing, have initiated new research into "Construction as a manufacturing process" (Koskela 1992, Tommelien et al 1999, Cooper et al. 2005). Tommelein et al (1999) go on to argue that production principles developed in manufacturing can be applied to construction since both construction and manufacturing can be considered as production systems including machines and crews as processing stations and hand-offs of partially completed work. Considering that very little work in construction research and management had gone into process modeling, Egan (1998) suggested learning from manufacturers who are accustomed to taking a process view of their operations and usually model both discrete product activities and holistic high-level processes for both internal and external activities.

Traditionally, a construction project's participants are referred to by their professional and expert status. The consequence of this traditional approach is poor communication and coordination commonly associated with construction projects. Contrary to this traditional approach, Process Protocol, a generic design and construction process, refers to the participants in terms of their primary responsibilities. This, as Cooper et al (2005) state, results in reduction of confusion and an increase in effective communication and coordination. This is a well-supported premise that will be adopted in this research proposal.

Cooper et al (2005) consider Process Management and Change Management as the two significant elements of the "Activity Zones" that include the other seven elements which are Development Management, Project Management, Resources Management, Design Management, Production Management, Facilities Management and Health and Safety, Statutory and Legal Management. Playing a critical role in the Process Protocol (outlined above), Activity Zones represent structured sets of tasks and processes which guide and support work towards a common objective. While planning and monitoring of each design and construction phase is under process management, change management holds responsibility for effectively communicating and propagating project changes to all relevant activity zones and the development and operation of the legacy archive. Change management responsibilities, as Cooper et al (2005) state, include:

- Receiving and structuring change information
- Distributing appropriate change information to relevant activity zones in an accurate and timely fashion
- Retrieving and distributing appropriate legacy archive information to relevant activity zones

- Reviewing and, where appropriate, modifying and/or updating the legacy archive.

The author of this thesis cannot agree more that Cooper et al “Activity Zones” and “Process Protocol” with their aforesaid characteristics have paramount importance in the construction projects. However, it can be argued that the structured set of tasks in the process management and also the points of change management responsibilities heavily rely on human being whose mistakes especially in repetitive tasks cause rework in the process which in turn results in delay. Therefore, the use of EPPMS (Electronic Product Process Management System), as an automated process tool where these repetitive human based tasks have been transformed to the machine based tasks holds considerable promise as an approach to addressing this gap in understanding and practice with respect to maintaining process compliance.

2.4 Definition of Process, Workflow, Workflow Engine, Database Management System (DBMS), Document Management System (DMS), and Cloud Computing

The terms *process* and *workflow* are used in this research. Therefore, a clear definition of these two terms is required. A process, as can be construed from the previous Section, includes a sequence of activities performed to achieve a particular objective [http://www.bpminstitute.org, last accessed: 5/1/2014]. Davenport (1993) divides processes into manual or human-based, or automated processes involving software and machines. So, a process can be completely manual, completely automated, or a combination.

First emerging in the mid-70s, a workflow, based on Bukovics’ definition (Bukovics, 2010; pp: 01) “*is an ordered series steps that accomplish some defined purpose according to a set of rules”*. In essence, a workflow, as a flow chart of actions is an outline of a business process with a clear start point, some sequential steps, and an end point. In manufacturing a workflow corresponds to the transport of partially completed products from one stationary machine to the next while in construction the product under construction are rather stationary and the crews from different disciplines come to the product site to complete their work which is being followed by the next crew (Tommelein et 1999). In the world of information technology (IT) Microsoft divides workflows as “Sequential” workflows and “State Machine” workflows. (http://msdn.microsoft.com/en-us/library/office/ms468447(v=office.14).aspx last access 6/16/2014). In the former, from initiation to completion of a process, the activities sequentially come to execution upon receiving a work item. However, the sequential workflows may include parallel logic flows based on which the exact sequence and the execution of activities may to some extent change. The latter, represents, a set of “states”, “transitions”, and “actions”. One state can serve as the start state and then tailored to an event, a transition can be made to another state and a final state can be determined as the end of the workflow. Muir (2013) states that all workflows, regardless of their types or number of steps, have one thing in common: “*forms as a means of interaction between users and activities”.* It means that forms are used to circulate information amongst the activities set based on logic and the users assigned to those activities. What orchestrates the flow of information from initiation to completion is a workflow engine.

As a key component in workflows and business processes, a workflow engine, based on Microsoft’s definition (http://msdn.microsoft.com/en-us/library/office/aa164772(v=office.10).aspx last access 6/16/2014) is a software tool or program used to enforce the workflow definition and execute workflow events. A workflow engine has three functions; (a) verification of the validity of a change for the current workflow state; (b) checking the current user’s authority to execute the workflow event; (c) evaluation of the validation script. For instance, in a change request workflow a reviewer, as the current user, intends to change the status of a change request in the reviewing stage, as the current state, from “reviewed” to “approved”. If the “approved” event is not defined for the current state, or defined but the current user is not authorized to approve the change request, the workflow engine would not execute that transition. If both the transition is a valid event and the user has the authority to do it, then workflow engine change the status from “reviewed” to “approved”.

Considering the definitions of workflow and process, in this research, a change management process is composed of several activities; such as “verify details” of change requests and “verify participants” by a coordinator, as a defined role (project team member), towards the approval or rejection of the CRs, as the defined objective. Change management workflow includes the steps, such as; the CR goes to a coordinator, then it goes to a review engineer.

As outlined before and explained in the next Section, processes and workflows are either manual, automated or a combination of both. As opposed to the manual processes which are independent from Information Technology, the automated processes are executable on the Internet. The Internet is a global system to link billions of computers and other IT-based devices together (http://en.wikipedia.org/wiki/Internet#Terminology, last accessed 6/16/2014). Due to its capability of peer-to-peer networks for file sharing, the Internet is the infrastructure and the platform for the workflow software applications based on which automated workflow-based processes are executed.

Considering the volume of data being shared amongst the users of automated workflows, a virtual inventory, where the data can be stored in, easily managed and modified, and timely extracted from upon the users’ request is a must. This is a point where Database Management System (DBMS) comes to life. The virtual inventory is called “database” and a collection of programs, software tools and applications to manage this virtual inventory is called Database Management System (Ramakrishnan & Gehrke, 2000).

Since the data in database is stored in a coding format, a “file viewer” or “document viewer”, as a software application, is required to decode the data in a human-friendly form and display the contents of the file or document on the screen, print it out on a paper, or read out with the aid of speech synthesis. File viewers are not able to edit files but they must have the compatibility with the format of the file to be viewed. In the Internet, web browsers are considered as a file viewer (Davis et al, 1992)

Relevant to Database Management System outlined above, is Document Management System (DMS) which refers to managing of electronic as well as paper-based documents in a computer-aided fashion. In the Internet and automated workflows, a document represents an electronic file that can be created with a word processer and may contain text, graphics, charts, tables, and other objects. Document Management Systems, regardless of their different types, include three components; an optical scanner to convert paper documents to an electronic form; a database system to organize the stored documents; a search mechanism to quickly find specific documents (Ramakrishnan & Gehrke, 2000).

Cloud Computing (CC) refers to both the applications delivered as services over the Internet and the hardware and systems software in the datacenters that provide those services (Kumar and Cheng, 2010). The services themselves are referred as *Software as a Service (SaaS)*, as the most common term, *Infrastructure as a Service (IaaS)*, and *Platform as a Service (PaaS)* (Armburst et al, 2010). The datacenter hardware and software is what is called a *Cloud.* In the Construction domain, all proprietary software systems, such as energy simulation system (daylight or HAVC simulation systems) or document management (management of contracts, building permits, purchase orders, regulations) could be on the public cloud whereas in the private cloud the project specific data and models like BIM will be stored and managed (Kumar & Cheng, 2010).

It is important to understand that the Construction Industry is moving towards the paperless office, and one of the areas potential for this move is management of changes where thousands of change documents are circulated amongst the stakeholders. Therefore, automated workflows with robust Database Management Systems and Document Management Systems are indispensable to this paperless change management approach. In addition, Cloud Computing is advantageous for construction projects being executed in remote locations or worldwide, since it makes possible for the stakeholders to not only have access to all necessary information hosted in servers (Cloud) but also to share and collaborate with the project data.

The last topic of this Section is how to graphically draw the processes and workflows. The author of this thesis has used BPMN (Business Process Model and Notation) as a standard for process modeling. Serving as a common language, BPMN is readily understandable by all technical and business stakeholders (Shapiro, 2011). As a drawing tool, Microsoft Office Visio™ 2013, due to the embedded BPMN environment, is used to draw the change management processes and workflows in Figure 4-1in Chapter four and in Figure 6-1 in Chapter six.

2.5 Levels of Automation of Change Management Process

To better understand the proposed model for implementing and continuously improving the automated change management process for construction megaprojects, the existing change management process models in the construction industry should be identified, evaluated and compared. The comparison not only shows the pros and cons of the current processes, but it can also lead to the hypothesis and the objectives mentioned on page 2 in this thesis.

Thus far, the construction industry, depending on the size, type of contract, scope, and complexity of projects, has experienced various models and methodologies for managing changes (Senaratne, Sexton 2011). For instance, the process and methodology of change management in a small "design-build" residential project may differ from that in a mega "Public Private Partnership" highway project. Regardless of their variety, change management processes are distinguished in three categories defined in this research. These categories as explained in the following are called

Generation One of Change Management, Generation Two of Change Management, and Generation Three of Change Management.

2.5.1 "Generation One" of Change Management

This category refers to managing changes through common paper forms, as a formal change document, circulated amongst those project stakeholders involved in the process of change management. As a conventional way in most of construction projects, Generation One would not utilize the Internet, computers, tablets, or other IT-based devices and heavily rely on faxes and "snail-mails" as a means of communication and document circulation. A change form with all attachments compiled in a file is physically sent from one location to another and it will be finally archived. Chronology or the order of occurrence of time and date stamps in each step of the process along with the stakeholders' orders and comments are often manually written on the margin of the change forms or attachments. An associated "Loose Process" may exist in managing of change. That is, the tasks to be done in the process of change management may not be clearly defined. As a result, depending on change type, the change file may either wander amongst a couple of tasks which in turn causes delay in the change management process or may receive unauthorized orders leading to, as Nalewaik (2012) calls it, "scope creep". Scope creep, defined as uncontrolled changes in the project's scope often leading to delay and cost overrun, may result from poor change control, blurred definition of project scope and project objectives, or poor communication amongst the stakeholders (Nalewaik 2012).

The "loose process", mentioned above, may gradually change to a "firm process" as the stakeholders (staff from the contractors and owners) gain experience and knowledge on how, depending on the change type, to follow the process's tasks from initiation to completion of the change management process. However, this firm process may become loose process again when this experience and knowledge is not properly captured and transferred from the old staff to the new ones.

While flawed, “Generation One” of change management is still dominant in the construction industry. In fact, one of the advantages of this process, as the author of this thesis has experienced in small and medium-sized projects, is the effect of the contractor’s representative presence in most of the tasks of the change management process, which in turn may reduce the time of negotiations and expedite the change evaluation. However, in megaprojects where hundreds of change forms are being circulated amongst many stakeholders, and time plays a critical role, this presence of the contractor’s representatives may not be effective and be considered as a waste of human resources. Therefore, more robust processes are required.

2.5.2 “Generation Two” of Change Management

“Generation Two” of change management utilizes the Internet and computers. Emails are used to circulate change forms and their attachments amongst the stakeholders in less than a couple of seconds. Therefore, the travelling time of a change form with its attachments between the contractor’s office and the owner’s office, regardless of how far or close they are located from each other, is negligible. This “zero” travelling time along with stakeholders’ accessibility to change files in any location where the Internet, computer, and email exist is an advantage over the “Generation One” of change management explained above. However, security is an issue since the confidentiality of the contents of change forms and their attachments will be compromised should the stakeholder’s email be hacked or incorrectly addressed or copied. As a “softcopy format”, change forms are usually made in the Word™ application of Microsoft Office Suite™ or by a proper electronic device (scanner), a “hardcopy format” (paper) of a change form and its attachments are scanned to a softcopy format. In most of the tasks or process states in “Generation Two”, the transition between hardcopy to softcopy and softcopy to hardcopy of change forms and the attachments often happens because stakeholders print change forms and attachments, add their notes and comments, and then rescan them. This may cause inconsistency in the process. It also leads to uncommunicated changes and thus confusion and waste. Spreadsheets are also typically used by stakeholders to manually update the status (time and date stamps in addition to comments) of the change. Like the process of “Generation One” of change management, mentioned above, the process of “Generation Two” of change management is a “loose process” even if defined on paper. Compliance and execution are based on manual tasks and human initiatives to move from one task or process state to the next. The “loose process” transforms to the “firm process” by the time when the stakeholders learn to whom their change form and the attachments should be emailed. However, like the “Generation One”, this “firm process” may change back to the “loose process” when new human resources enter into the process and have to relearn the process. The main difference between “Generation two” and “Generation One”, when compared, is the utilization of the Internet, computer, and email in the former, which is claimed to reduce the change management process duration due to zero travelling time of change forms from initiation to completion of the process. However, the missing attachments in the trace of the emails concerned with change management process, the inconsistency in the process due to transition of softcopy to hardcopy or hardcopy to softcopy, or even typos or inaccurate status of change updates in spreadsheets have one common factor; manual tasks and human initiative which in turn is prone to mistake and leads to rework in the process. These flaws may not be fatal in small to medium-sized projects, therefore the “Generation Two” approach may work, but in megaprojects where hundreds of changes happen, a robust automated workflow-based process is required to circulate the forms and their attachments amongst the hundreds of stakeholders with consistency and in a timely manner.

Both “Generation One” and “Generation Two” of change management have already been compared together by Charoenngam *et al* (2003). In their research, based on two forms of contracts; ICE (Institution of Civil Engineers) and FIDIC (Fédération Internationale Des Ingénieurs-Conseils/International Federation of Consulting Engineers) Charoenngam *et al* (2003, p:197) they introduce *“change order management system (COMS)” a “web-based project management system”* and in a case test they compare it with *"the conventional practice of change order management*". Neither the details of how his COMS works nor the detailed procedures of the aforesaid contracts are in the scope of this thesis. Therefore, it is sufficient to show the results of comparison made in the case test (Table 2-1). Note that the schedule savings hypothesized are due almost entirely to reduction in mailing time from "snail-mail" to email. Neither queuing times nor rework is included. Nor are conflicting job functions for those processing the change requests acknowledged.

Although designed to facilitate the change order process and improve the accuracy, timeliness and the cost of the process, the change order workflow for the web-based process, as Charoenngam et al (2003) claim, slightly differs from the traditional method. Charoenngam et al (2003) state that actual negotiations and agreements are not facilitated by the COMS and cost and time issues must still be settled through meetings or other traditional means. The COMS system is claimed to aid in the following:

- usage of a standard set of forms for each activity in the facilitation process;
- prompt delivery of the documents to the addressed construction participant;
- means to know if the other party has read your sent document;
- no conflict between the parties due to the loss of particular forms through a common centralized database distributing the identical form of a particular document
- avoidance of documents mismanagement

The author of this thesis argues that the COMS is still prone to human mistakes since the circulation of the change document, although electronically (web-based) processed, relies on human clerical activity. For instance, an email of a change order can be sent back to the sender due to the wrong delivery to the manager instead of the lead engineer, or an attachment is missing in the email sent. As stated above, these situations, happening frequently, lead to rework, which in turn results in delay in the change management process of projects and especially megaprojects. Therefore, an automated workflow-based process to minimize or eliminate the rate of rework is required. The next Section defines such a process as “Generation Three” of change management. It is an automated workflow-based process.

Table 2-1: A comparison of the total duration to complete the change order process in conventional method and COMS method by Charoenngam *et al* (2003)

Activities	Duration in Conventional Method	Duration in COMS Method
Contractor sends a change order request	2 days	1 day
Architect/Engineer acknowledges COR and requests for a COCP	2 days	1 day
Contractor prepares a change order: cost proposal	2 days	1 day
Architect/Engineer assesses COCP, determines an agreeable price and time	2 days	1 day
Owner assesses COAA, affixes signature for approval	2 days	1 day
Contractor creates a COIR for change order work assessment	2 days	1 day
Total time consumed	12 days	6 days
COAA: Change Order with Architect/Engineer Approval, COR: Change Order Request, COIR: Change Order Interim Report, COCP: Change Order Cost Proposal		

2.5.3 “Generation Three” of Change Management

The practicality of “Generation Three” of change management depends on the Internet, computers, workflow engines, Database Management Systems (DBMSs), Document Management Systems (DMSs) and cloud-based software applications. These elements are all explained in Section 2.4 of this Chapter. The integration of these elements works as a platform in “Generation Three” of change management process. As a result, in the process of change management, stakeholders require only a web browser to interact together through this platform (Figure 2-4).

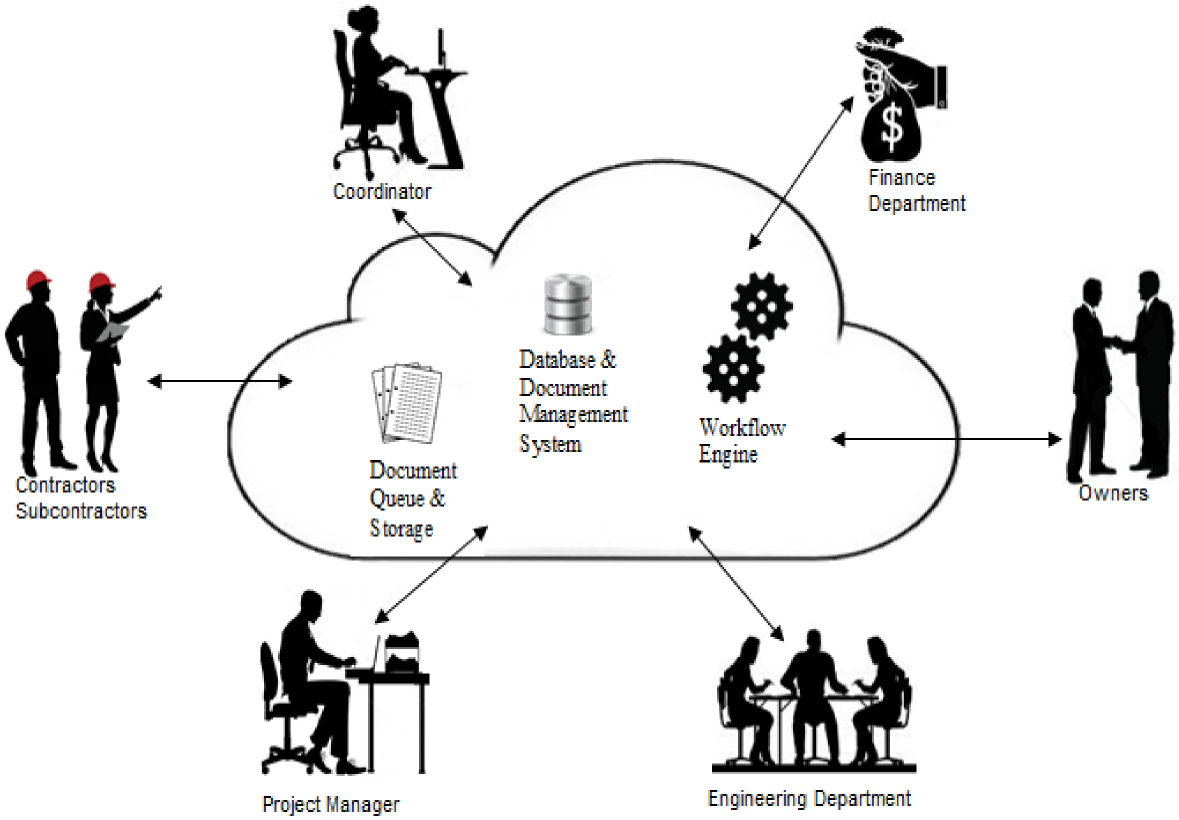


Figure 2-4: Project stakeholders' interaction in "Generation Three" of change management

The existence of this platform, including workflow engine, database and document management system, causes the change form and its attachments to be delivered to the right person assigned to receive the change form in the change management workflow steps and stored in the right file. Automated workflows are implemented for repeatable events not for something that happens only once. For instance, if defined properly in the change management workflow, all change forms up to $5000 worth of change will be directly sent to accounts payable, whereas those change forms of more than $5000 will be sent to the manager for further approval. Due to automatic initiation of activities and automatic document distribution through the workflow engine, no change form more than $5000 will be mistakenly sent to accounts payable without the manager approval. Hence, the rate of rework in the change management automated workflow would be minimized and compliance with corporate and project practice definitions is improved. This change form delivery with no rework is called “lean delivery”.

2.6 Roles and Responsibilities in a Change Management Process

The Construction Industry Institute (CII)’s research report (CII RT-244, 2011) introduces “Project Controls and Management Systems (PCMS) Participants Involved Tool” as a tool to identify the organizations that might be participating in each function-phase, as well as which organization has leadership responsibility. It is directed to large or mega industrial projects. In any specific project, the tool could be modified according to the lead participant and the active participants identified in each function and phase. In Table 2-2 the key participants in change management, as one of the functions in project phases, have been identified.

Table 2-2: Project Phase-Function Participants (CII RT-244, 2011, p: 21)

PHASE	PROJECT PHASE: Front End Planning	Design	Procurement	Construction	Start-up
Change Management	Business Owner Owner Project Management Owner Engineering Engineering Contractor	Business Owner Owner Engineering Engineering Contractor Engineering Subcontractor Construction Contractor Major Equipment Vendors Supply and Erect Vendors	Owner Engineering Engineering Contractor Engineering Subcontractor Major Equipment Vendors Supply and Erect Vendors Vendors	Owner Project Management Engineering Contractor Construction Contractor Supply and Erect Vendors Vendors Subcontractors	Owner Operations Owner Engineering Owner Project Management Construction Contractor Vendors Start-up Contractors
Progressing	Engineering Contractor	Owner Engineering Engineering Contractor Engineering Subcontractor Major Equipment Vendors Supply and Erect Vendors Construction Contractor	Engineering Contractor Engineering Subcontractor Major Equipment Vendors Supply and Erect Vendors Construction Contractor Vendors	Engineering Contractor Construction Contractor Supply and Erect Vendors Vendors Subcontractors	Owner Operations Owner Engineering Owner Project Management Construction Contractor Major Equipment Vendors Start-up Contractors
Forecasting	Business Owner Owner Project Management Owner Engineering Engineering Contractor	Owner Engineering Engineering Contractor Engineering Subcontractor Major Equipment Vendors Construction Contractor Supply and Erect Vendors	Engineering Contractor Engineering Subcontractor Major Equipment Vendors Supply and Erect Vendors Construction Contractor Vendors	Engineering Contractor Construction Contractor Supply and Erect Vendors Vendors Subcontractors	Owner Operations Owner Engineering Owner Project Management Major Equipment Vendors Supply and Erect Vendors Construction Contractor Vendors Start-up Contractors

As shown in Table 2-2, moving forward from the Front End Planning phase to Start-Up, key participants change from “Owner Project Management” to “Engineering Contractor” and again back to "Owner Project Management" (the roles bolded and underlined). Like the roles, the responsibilities defined for the roles could be specified and modified in line with the type and requirements of the project. Appendix F shows the responsibilities defined for each role involved in the project. This table defines the roles from the owner side. However, "Generation Three" change management, explained in Section 2.5.3, can be constructed from an owner's or contractor's point of view.

2.7 Industry Approach to Change Management

In order to effectively and efficiently manage changes in the construction projects, the Construction Industry Institute (CII), a non-profit consortium of more than 100 owner, engineering-contractor, and supplier firms from public and private sectors (www.construction-istitute.org) , has introduced five principles to follow. They are paraphrased and described below, along with commentary on how they relate to other change management principles described in this literature review.

- *Promote a balanced change culture:* as the first criterion, this will not only encourage those changes to proceed that will clearly benefit the project end user, but it also will discourage or prevent adoption of changes that do not meet this objective. What may seem beneficial to some stakeholders could be detrimental to others. Finding a fine line of satisfaction and unanimous agreement amongst the stakeholders is, therefore, extremely difficult (Winch 2010). Two sub-criteria would lead to a balanced change culture:
    - *Encourage beneficial change*: beneficial change is NOT necessarily related to immediate and positive impacts, yet no long-range negative impacts occur in the project life cycle.

    - *Prevent/Discourage Detrimental Change*: reducing owner value, detrimental changes usually have a lasting effect and tend to make the team resistant to the change process.
- *Recognize Change:* this requires an environment where team members openly interface and communicate with one another. Interface and interface management, as a plan, is the oversight of interactions and information flow between the major contracting parties on large capital projects. Managing interface communication includes a) interface points identification, b) interface agreement, c) Action items, and d) Change request which in turn includes d-1) request a change to an existing interface agreement and d-2) change register (Shokri et al, 2012). Considering this, the author of this thesis argues that interface management is one of the cornerstones in recognizing and managing changes in the project life cycle and better interface management results in fewer numbers of change requests and better change management as a result. The definition of the scope of work is of paramount importance to identify and manage change, because the project scope is tied back to a unanimous agreement upon schedules, budgets, commitments, and accountability for recognizing change.
- *Evaluate Change:* as shown in the following it is classified as *required* and *elective.*
    - *Required Changes:* it must be implemented due to their necessity to meet basic business objectives, to meet regulatory or legal requirements, or to meet defined safety and engineering standards.
    - *Elective Changes:* proposed to enhance the project, but not required to meet the original project objectives, elective changes are not mandated and may or may not be implemented. These changes are allegedly to be beneficial; however their long range effects again should be considered and investigated.

- *Implement Change:* sufficient flexibility of the project team to implement a change at any point in the project schedule is a must. This principle, as CII (1994) states, requires:
    - *Authorization:* it means that the change must be or can be implemented, and that all items that are required prior to implementation have been met.
    - *Documentation:* this requires a method to follow up on the overall impact of the changes. Frequent status updates will provide better knowledge and control of changes.
    - *Tracking:* it is valuable when the project team desires information on the timing aspects of the change process. It is worth mentioning that timing, along with measurability, significance, influence and repeatability are the criteria for the metrics considered as a measurable outcome based on which the efficiency and effectiveness of change management process could be measured.
- *Continuously improve from lessons learned:* project strategies and philosophies should take advantage of lessons learned from past, similar projects. Given that metrics are developed and implemented and targets are adjusted to remain meaningful, the process should benefit the project at hand and document lessons learned to continuously improve future projects. This is the right point where the "Generation Three" of change management system fits in since it enjoys an automated workflow-based approach towards change management. In other words, due to the nature of a process, a "Generation Three" of change management can function as a cycle in which the path that changes will move back and forth is identified. Hence, the system can provide feedback by which system improvement will be gained.

Given the aforesaid principles, effective change management is the result of having all these principles followed so that the process flows forward smoothly. However, it can be argued that these principles are not comprehensive and may lead to ineffective change management. For instance, the process of negotiation is ignored, while it is an inevitable part of change management, and it is a common method of dealing with construction disputes (Chen & Hsu, 2007). This issue will be considered and examined in a Generation Three of change management process.

2.8 Information and Knowledge Flow in Change Management

Zhao et al (2010) argue that change management is a function of information flow. Therefore, according to their theory, a better control of the information flow would result in better change management. One information model for change management, for instance, provides the representation of dependencies between the activities in order to identify the *ripple effect* (Hegazy, Zaneldin & Grierson 2001) and its scope which happens when the change of one activity triggers further changes to other activities surrounding it (Park, Peña-Mora 2003). In a formation of the ripple effect, Karim and Adeli (Karim, Adeli 1999) presented a generic IT system based on an object oriented information model for construction scheduling, cost optimization, and change order management. Further, during the actual change process, two types of information flow exist; Activity-Based Information Flow (AIF) and Non-Activity Information Flow (NAIF). The sources of the former are project schedule and Gantt chart, while the latter originates from environmental factors, legal issues, governmental rules and staff and labor factors (Zhao et al. 2010). Senaratne and Sexton (2009) also argue that to effectively manage the project changes, capturing and managing project team knowledge is of paramount importance. Their research states that the process of transferring project team members' tacit knowledge, usually visualized during discussions when team members share their previous experiences, is the cornerstone of managing unexpected changes. Although the importance of information flow and capturing knowledge in change management is supported by the preceding arguments, what is lacking is an automated workflow-based process, such as "Generation Three" of change management process in which the information accurately circulates among the project team in a timely manner. The “lean delivery” example, explained in Section 2.5.3 justifies how “Generation Three” of change management can fill the lack in the information flow outlined above.

2.9 Change Prediction and a Proactive Approach towards the Change Management Process

When change is considered as one of the major causes of cost increase and project delay, the prediction of changes in a timely manner is a proven advantage for the project management team. Kartam (Kartam 1996) states that finding the problems and probable changes at the earliest stages of the project life cycle would lead to minimizing potential conflicts. Kartam (1996) goes on to introduce Interactive Knowledge-Intensive System (IKIS) for constructability, a system to identify feedback channels in a project life cycle in order to integrate the lessons learned from the further phases at the earlier phases of the project life cycle. The author of this thesis, however, goes on to argue that although the lesson learned system can be of assistance to minimizing conflicts in similar projects, this system cannot be reliable in megaprojects due to their complexity and one-off nature. In other words, these projects have the potential for changes and conflicts which are unprecedented.

The Dependency System Matrix (DSM) is a tool for predicting changes occurring in the project life cycle (Zhao et al. 2010). Zhao et al (2010) state that DSM is essentially used in the design phase which is iterative in nature and uses network-based tools such as critical-path method (CPM) and program evaluation to program the project activities and the relations between them. The DSM functionality relies on Activity-based Information Flow (AIF) and Non-Activity Information Flow (NAIF). When it comes to AIF, as Figure 2-5 shows the matrix consists of the activities listed down the left side, one per row with an associated number. The matrix diagonal is shaded since no activity has the potential change influence on itself.

Figure 2-5 and Figure 2-6 in the matrix represent the information flow between two activities. Reading across a row reveals the sources of inputs to an activity and reading down a column indicates the outputs of an activity. "Zero" means that the correlation between activities is the weakest while "1" indicates the strongest correlation between them.

	Act 1	Act 2	Act 3	Act 4	Act 5	Act 6	Act 7
Act 1							
Act 2	0.5						
Act 3		0.3					
Act 4			0.4				
Act 5			0.4	0.2			
Act 6							
Act 7							

Figure 2-5: Dependency structure matrix (Zhao et al, 2010 p: 661)

However, this system cannot be used in the construction phase where whatever is set in the design phase goes into practice. Also, what is overlooked here is an automated process to manage and control the changes and to define who is accountable to approve the change, should it happen. Hence, "Generation Three" of change management process, as explained in Section 2.5.3 is required to overcome these deficiencies.

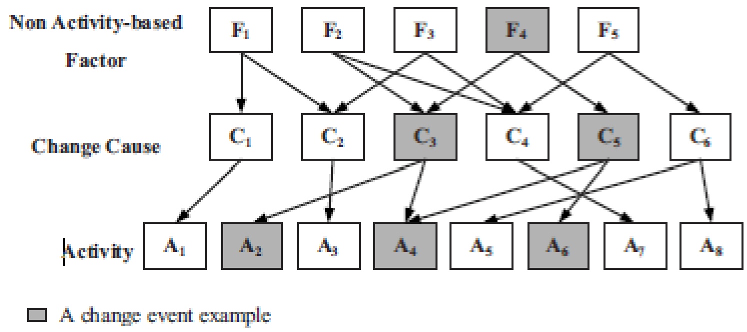


Figure 2-6: Dependency diagram for a change event example (Zhao et al, 2010 p: 663)

In related research (Maheswari, Varghese & Sridharan 2006) contend that due to the knowledge intensive forms of DSM, experienced experts are required to judge the impacts of NAIFs on certain activities. This knowledge could be gained through interviews and questionnaires and utilized in DSM with fuzzy logic theory. Although it seems correct in theory, the author of this thesis argues that this method is highly impractical. Since it is dependent on a non-automated process and an old system of data collection, it is time consuming and costly. This, however, can be an opportunity for the automated workflow-based process for change management to attempt to automate or quantify it.

2.10 A Vendor's Approach to Change Management

The "Generation Three" of change management process has been implemented by at least one company. Coreworx^{TM} Inc. has implemented a solution which is explained in the following Sections. Coreworx^{TM} is a partner in the research described in this thesis.

2.10.1 A Vendor Introduction

With a vision to revolutionize capital project execution through the deployment of world-class project information management solutions, Coreworx^{TM} (www.coreworx.com) is a 10-year-old Kitchener-based enterprise software company that equips the owners and EPCs (Engineering, Procurement, Construction), mainly involved in oil and gas, power, mining megaprojects, with state-of-the-art document management systems and solutions. Coreworx^{TM} software packages, such as change management and interface management are being used by 70,000 users, in 500 projects with total value of $700 Billion in almost 40 countries throughout the world. These figures shall not only provide evidence for the importance of Coreworx's services in numerous capital projects being executed remotely in the construction industry internationally, but they shall also validate the notion that the "Generation Three" of change manage process has the potential to be one of the significant attributes of the success in these types of projects in the near future.

2.10.2 A Vendor's Management of Change System

Coreworx^{TM}'s change management System is focused on the owners and not the contractors, although, as stated at the end of Section 2.6, the change Management process can be constructed from an owner's or contractor's point of view. Coreworx^{TM}'s change management process provides an open environment where project team members can submit a change request for prompt evaluation and classification. A preliminary assessment of potential impacts as well as identifying document requirements results in either an approval or rejection of the change request. All affected parties are informed of the change request, and real time monitoring of key metrics provide complete traceability for every approved change.

The Coreworx^{TM}'s change management system is intended to capture information about a change request and move it through a review cycle to assess impacts of the change. Every change creates a responsibility matrix that identifies the appropriate coordinator, approver, participants, and informed work group based on the change type, assessed cost and scheduled delay.

The Coreworx^{TM}'s change management system offers several web parts. Comprehensive reports for project managers create an interface to effectively monitor and control changes. Change metrics (Figure 2-7) equip project managers with a snap-shot of the number of changes and the total value of those changes. Further, the snap-shot can be separated to correspond to the four main states of any change request; *approved*, *Pending*, *New*, and *Rejected.* A change summary report would include detailed information about a set of project changes.

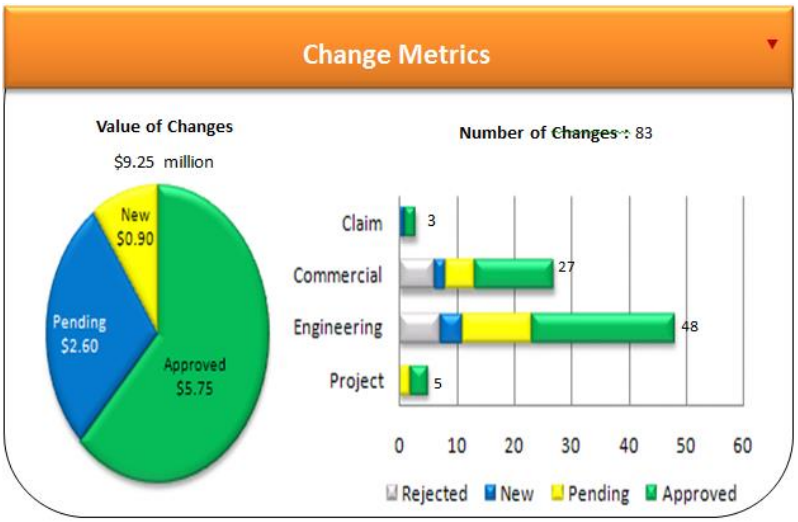


Figure 2-7: Change metrics elements (courtesy of Coreworx)

To support management of change, Coreworx™ uses three separate processes;

1. Change Request (CR): it starts when a project team member raises a change request form upon identifying a proposed change. Here, the project team can be defined as a team including engineers, designers, contracts and procurement administrators or those who have a direct and technical responsibility to the execution of the project. These individuals are accountable to a project manager (or a team of project managers) who is directly accountable to the owners and financiers of the project. The issued change request may need approval by those who are authorized to review, assess, and make a decision on the approval or the decline of the change request issued. Some change requests, however, do not require board approval, since they are initiated from the field. This is because different industries and different organizations have different approaches to demarcate the formality and informality

of change process in order to save time and cost in a change and project life cycle. For instance in a nuclear project, every change, regardless of how minor or major it is, should be done through a formal process whereas in a mining process, minor changes (substitution of one type of excavator with another) may be accepted through an informal process.

2. Variation Request (VR): generated by the contractor, Variation Request is the area where most of Management Of Change (MOC) activity will take place. In essence there is no considerable difference between the Change Request and Variation Request, but the former is issued from the project team (defined above) and the latter from the contractor.
3. Variation Order (VO): with the aim of formalizing the instruction to proceed with a variation and confirming the agreed cost and schedule impact, this process would be initiated.

The change request process is an internal process. In other words, it is not within the access of external project contracted parties to initiate a change request. The change request uses the Coreworx™ "out-of-the-box" (i.e. without intervention from the costumer) module, packaged with a defined form, Document Management System archive, workflow and set of reports.

As for the Variation Request, the contractors can use the form within the contract to initiate their request for a variation and the relevant Commercial Supervisor (first line of approval administrator) will be the key player in the variation process with Coreworx™. The Variation Request will be imported into a designated archive containing the following data fields to be used for tracking of the Variation Request.

- Contractor's Variation Request No
- Corresponding Coreworx Variation Request No
- Date Received
- Description (Title)
- Reference Documents

- Requested Cost Impact
- Requested Schedule Impact
- Estimated Cost Impact
- Estimated Schedule Impact
- Probability of Estimated Cost Impact

The last three data fields are done by a reviewer or assessor under the project manager through a set of practices for the identification, estimation and assessment of the impact.

2.10.3 Key Roles in the Change Request Process and Workflow

As the essentials of the "Generation Three" of change management process, workflow engines, Database Management Systems (DBMS), Document Management Systems (DMS) and cloud computing, were defined in Section 2.4. Beside these key elements, as shown in Figure 2-8, there are some key roles also involved in the process of change management and change requests:

1. The "initiator", who could be a designated project team member, initiates the process by submitting a change request, an electronic form that includes all change details, potential impacts and attached documents.
2. The "coordinator" not only reviews the "Change Request" form to ensure sufficient information is provided but also reviews the assigned list of participants and makes any appropriate modifications to the list.
3. The "manager" reviews the details of Change Request, adds the proper comments or recommendations, and eventually determines whether to send it to participants for review, or send it for approval or reject it. Considering one of these statuses, the following happens:
    a. Send for approval: process continues to step 6
    b. Send for review: process goes to step 4

   c. Reject: Change Request is cancelled and notifications are sent to "informed stakeholders", as one of the key roles, and the coordinator confirms completion of all items on close-out checklist.

4. "Responsible project team participants" review the Change Request and provide more detailed information such as estimates, comments, document markup and schedule updates, as required.
5. The "manager" reviews the consolidated participant comments and recommendations, adds his/her own comments or recommendations, and determines whether to send the CR request for approval or to reject it.
6. The "approver" reviews the Change Request comments and recommendations and determines whether to approve the Change Request or reject it. In case of approval the following step proceeds
7. If the Change Request requires external party approval, the coordinator sends the Change Request information with any commercial details to the external party.
8. The external party reviews the information and sends their approval or rejection. In case of approval the process continues to the following step.
9. The coordinator verifies the accuracy of the external party information and finalizes the Change Request
10. Change Request becomes an Approved Change and notifications are sent to Informed Stakeholders.
11. The "coordinator" confirms completion of all items on implementation close-out checklist.

The initiator, coordinator, reviewer, approver, and manager are the members of the project team as defined above. External parties and informed stakeholders, as Winch (2010) states, are those who are indirectly involved in the process of project and by and large do not have technical responsibilities to the execution of the project, but they should be informed on the changes happening in the project life cycle. Figure 2-8, a change request process diagram, demonstrates the above roles and steps. It is important to know that Figure 2-8 does not represent a workflow diagram, but its workflow implementation will be defined later.

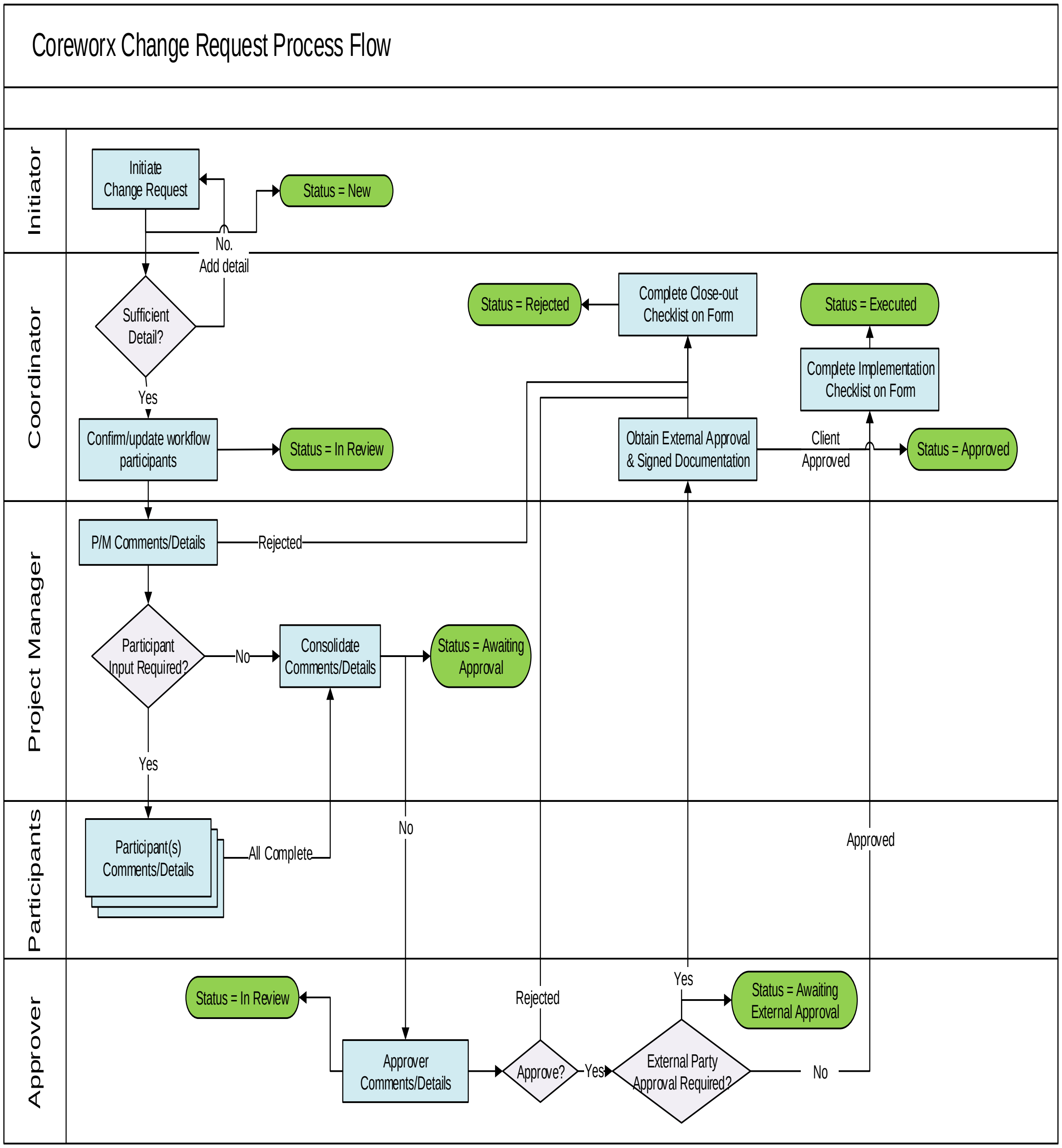


Figure 2-8: Change Request Process Diagram (Courtesy of Coreworx™)

2.10.4 Change Reports

Coreworx™ change management process is able to provide project team members with change reports including change log, cost detail sheet, status report, and commitment report defined as follows:

- *Change Log:* by definition a change log is a record of Requests For Change (RFCs) submitted for all changes in the project. A change log tracks the progress of each change request from submission through review, approval or rejection, implementation and closure. In "Generation Two" of change management process the log can be managed manually by using a document or spreadsheet, but in "Generation Three" change management process the update status of changes in the log can be managed automatically with Database Management System (DBMS) as explained in Section 2.4. As contractors submit change proposals (in response to either new or revised drawings, field changes, site instructions, etc.) each change proposal is entered into the Change Log per the attached. Prior to this step each of the change mechanisms, such as a drawing's site instructions, have their own logs, and each issue of the change mechanism is entered into their respective logs.
- *Cost Detail Sheet:* reflects the accumulation of approved changes as they are included in Contract Modification.
- *Status Report:* this report is provided to summarize all of the pending and approved changes and compare them against the Authorized Contract Value for the purposes of forecasting.
- *Commitment Report:* this report accumulates the negotiated savings from the "Change Log" (Proposed vs Agreed). Negotiated Savings can be accumulated by Contract, Project, Office or Company Levels.

The previous Sections explained different processes of change management in the construction industry and a vendor's approach towards a workflow-based process for managing changes in megaprojects. This "Generation Three" system has the functional and compliance advantages described above.

Before concluding this Chapter, it is important to know the importance of simulation and especially Discrete Event Simulation (DES) to model construction projects' processes and whether or not it is an appropriate tool to be used to model, understand, analyze, and compare change management processes. The next Section addresses these issues.

2.11 Discrete Event Simulation (DES) in Construction Projects' Processes

For decades, process industries, such as manufacturing, have widely applied discrete event simulation and its tools to improve production processes and production scheduling (Vaidyanathan et al, 1998). As stated before, construction projects execute repetitive processes, and over the past 20 years simulation has been used to model, analyze, and improve these processes primarily from a physical work perspective (Wang et al, 2009). Martinez (2001) introduced EZStrobe, as a simulation tool following the CYCLONE process-based methodology introduced by Halpin (AbouRizk and Hajjar, 1998), to simulate construction cyclical processes based on Activity Cycle Diagrams (ACDs). In his research, EZStrobe was employed to model an earthmoving operation where an excavator sequentially loads some trucks at point "A" and then the loaded trucks dump the soil in point "B" and return to point "A" to reload. As the output of the simulation model, the idle time of the excavator and the waiting time of the trucks to be loaded could optimize the number of trucks and excavator, leading to improving the earthmoving cyclical process.

In their research, Wang et al (2009) simulated a spool fabrication shop's production process based on assembly, batch, and unbatch. Symphony™, developed based on a specific purpose simulation (SPS) modeling (Hajjar and AbouRizk, 2002), was used to model the layout of the fabrication shop. The change in the fabrication layout improved the production process in a way that there were less traffic, no bottlenecks, and less inventory.

Due to both repetitive and linear project planning, tunneling as Hajjar and AbouRizk (1998) state, can easily utilize simulation. Considering the quick and data-rich exploration of simulation "What if" scenarios, Al-Bataineh et al (2013) used simulation in two stages of a tunneling project. The simulation model results in the planning stage proved that the two-way tunneling, as the common wisdom, would not be right choice. During the execution stage, the outputs of the simulation model showed that the installation of a switch might regress rather than progress the project.

In line with the importance of simulation in construction, AbourRizk (2010) introduces "Construction Synthetic Environment Framework" to *achieve a fully integrated, the highly automated construction modeling and simulation model deployable across the design and construction phases in the life cycle of a facility* (AbouRizk 2010; pp 1147).

Combined with genetic algorithms, simulation can potentially be an effective tool to improve planning and resource management in large-sized construction projects (Hegazy & Kassab, 2003). In their approach, Hegazy & Kassab (2003) used Process V3™, a simulation software application, and implemented a GA-optimized simulation model in a concrete-placing and an earth moving operations. Linked to the lower elements of the Work Breakdown Structure (individual construction operations) of the aforesaid projects, the GA-optimized simulation model can optimize the number of resources leading to the best benefit/cost ratio.

Closer to this research is the use of simulation in invoice management in construction projects (Younes, 2013; Younes et al, 2014). To identify the bottlenecks in the invoice process (manual and electronic) and to minimize the invoice delay, Younes (2013) modeled two invoice processes; an electronic process from an oil and gas company and a manual process from a major homebuilder. Younes (2013) identified five categories of waiting time in the current invoice processes. “Batch effect” defined as the accumulation of invoices in each station, and “resource availability” defined as the waiting time of invoices prior to being evaluated by individuals, were considered as the most affecting bottlenecks along with rework, control station, and inconsistent flow of invoices leading to overdue invoices. The simulation results indicated that the implementation of the electronic system, due to its continuous flow of invoices and the elimination of the queue time, would improve the invoice process.

2.12 Summary

This Chapter considered the definition of change, causes of change, and change management process as a methodology to manage changes. The study of academic sources, such as journal papers, websites, and books relevant to the research in this thesis, identified the knowledge gap; the lack of an automated workflow-based process to more effectively manage changes in construction megaprojects. Charoenngam et al’s (2003) Change Order Management System (COMS) represents a web-based change management process based on which change documents are electronically circulated among the project team members via email. Cooper et al (2005) introduced process management and change management with a structured set of tasks in their “process protocol” for the construction projects. Emphasizing the importance of capturing of project team members’ tacit knowledge or “know-how” (Schmidt 1993; Cardinal 2001) and information flow in managing changes, Zhao et al (2010) introduced a Dependency System Matrix the functionality of which relies on Activity-based Information flow (AIF) depending on Critical Path Method (CPM) and the relation between the project activities and Non-Activity Information Flow (NAIF) depending on the experts whose knowledge can be captured through interviews and questionnaires. Considering these key advances and related research, two categories of change management process were defined: “Generation One” and “Generation Two”. “Generation One” represents those change management processes that are pre-internet and use common change paper forms faxed or snail mailed by project team members from one process state to the next. “Generation Two” represents those change management processes in which the Internet and computers are used and common forms of change in a scanned softcopy format are being emailed by project team members from one process state to the next. Both “Generation One” and “Generation Two”, processes are “loose processes” sometimes defined on paper and compliance and execution are based on manual activities and human initiative. The dependency of these processes on human being whose mistakes, especially in repetitive tasks, may cause rework and delay in change process necessitates the existence of an automated workflow-based process where the repetitive human-based tasks are transformed to the machine-based tasks which in turn should lead to less rework and more compliance. This automated workflow-based process was defined as “Generation Three” of change management which is based on the use of computers and the web browser of the Internet by project team members to transfer change information from one process state to the next. Unlike “Generation One” and “Generation Two”, “Generation Three” infrastructure and execution is based on workflow engine, Database Management System (DBMS), Document Management System (DMS), and cloud based applications. Therefore, as hypothesized in this thesis, in “Generation Three” the rework and delay in the change management process is minimized, compliance and accuracy in change evaluation is increased, and change documents are circulated in a timely manner, since the repetitive tasks are taken away from the human’s hand and left with machine’s hand. Following “Generation Three”, the change management solution of Coreworx™, a vendor and a partner in this research, was introduced.

There are knowledge gaps in understanding the mechanisms of “Generation Three” systems; how they impact compliance, transparency, and performance of change management; and how they differ fundamentally from previous generation change management systems. How to continuously improve these automated change management processes and systems using the capabilities provided in “Generation Three” systems is also not known.

Finally, the value of discrete event simulation (DES) in construction research was explained. DES is a useful tool to model a change management process. Considering this, the next Chapter proposes a methodology and metrics to meet the main objectives of this thesis, as defined in Chapter one.

Chapter 3
Proposed Methodology

This Chapter introduces the proposed methodology and the metrics required to meet the main objectives defined in Chapter one. In Section 3.1 the first main objective needs a clear definition of tasks and steps in each of three generations of change management processes, defined as Generation One, Two, and Three in Chapter two. To meet the second main objective, in Section 3.2 a continuous improvement process program (CIPP) is introduced. Section 3.3 includes proper terminologies of workflows. Section 3.4 highlights the relation between the RFI, CR, and PCN processes. Section 3.5 covers the metrics and measurements to evaluate and calibrate the change management process. Finally, Section 3.6 explains in detail why and how DES is used to develop a simulation model for the change request workflow used in a Canadian oil and gas project, selected as the case study in this research, and it introduces Simul8^{TM} as the selected simulation software package to model the aforesaid workflow.

3.1 Meeting the First Main Research Objective

In Section 1.2, the two main research objectives along with the sub-objectives were explained. In Section 2.5, based on the literature review, the existing change management processes in the construction industry were categorized as "Generation One" and "Generation Two". Following these, "Generation Three" as the proposed change management process was introduced. To meet the first objective: *evaluate and quantify the difference in performance between the levels of automation of change management processes*, a comparison between these three different generations is required. A detailed definition of the tasks in the change management processes of these generations may result in more accurate comparison. Tasks, in general, are defined as human-based tasks and machine-based tasks (see also Figure 3-1 for human-based and machine-based tasks in a workflow). In "Generation

One”, all tasks in a change management process such as physically mailing a change document are human-based tasks. Although in “Generation Two” some tasks, such as the transformation of change documents from hardcopy to softcopy is a machine-based task, manually updating the change document status in the change log in each process step remains as a human-based task. In “Generation Three”, updating the change document status in the change log is machine-based while one-off tasks such as negotiations like in “Generation One” and “Generation Two” remain as human-based tasks. When the above tasks in the three levels are compared, it shows that in moving from “Generation One” towards “Generation Two” and then “Generation Three” the level of machine-based repetitive tasks increases while the level of human-based repeatable tasks decreases, as shown in Figure 3-1: human-based vs Machine-based tasks' levels in different levels of change management process. However, the analytical, judgment, and communications work of the professionals involved remains largely the same.

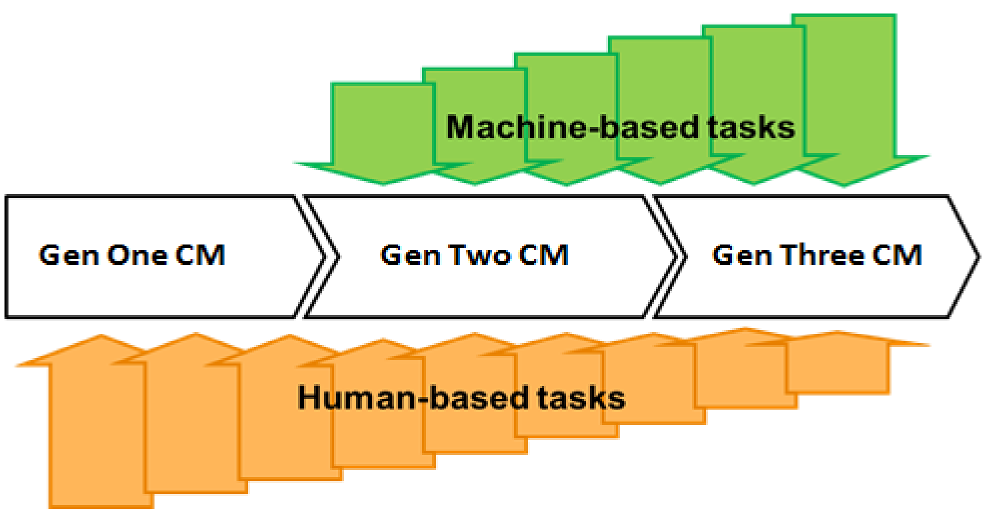


Figure 3-1: human-based vs Machine-based tasks' levels in different levels of change management process

Shifting from “Generation One” and “Generation Two” towards “Generation Three” of change management may lead to less rework and more compliance which in turn may lead to reducing the change evaluation duration. To prove this, the first objective of this research, reiterated at the beginning of this Section, should be met. Ideally, a construction megaproject in which these generations of change management processes are used is required since it permits an “apples to apples” comparison and delivers more accurate results. Access to such a project was facilitated by Coreworx™, the partner of this research. The details of this megaproject are explained in Section 4.1. To extract the proper data required to quantify and compare “Generation One”, “Generation Two”, and “Generation Three” change management processes, two main sources of data were available: Database and change logs, and interviews with the project experts. The former provided empirical data mostly related to the duration of change documents evaluation while “Generation One”, “Generation Two” and “Generation Three” were respectively in operation. The latter was conducted to get better insight about the roles, tasks, and number of project team members in each task of the change management processes especially for “Generation One” and “Two”, since the proper data about these two processes was not as systematically recorded as it was in the database of “Generation Three”. The details of the megaproject and sources of data are explained in Section 4.1.

3.2 Meeting the Second Main Research Objective

To meet the second objective, *develop and validate a model for continuous improvement of automated change management processes as per defined metrics*, a continuous improvement process program (CIPP) is considered. A CIPP includes the following characteristics:

- Formal
- Documented
- Continuous and Periodic
- Used by management for key business decisions

A CIPP is designed to achieve Critical Success Factors (CSFs) defined as the following:

- A repeatable process for making changes
- Make changes quickly and accurately
- Protect services and data when making changes
- Deliver process efficiency and effective benefits

A CIPP for a "Generation Three" workflow-based system includes the following cyclical activities as shown in Figure 3-2.

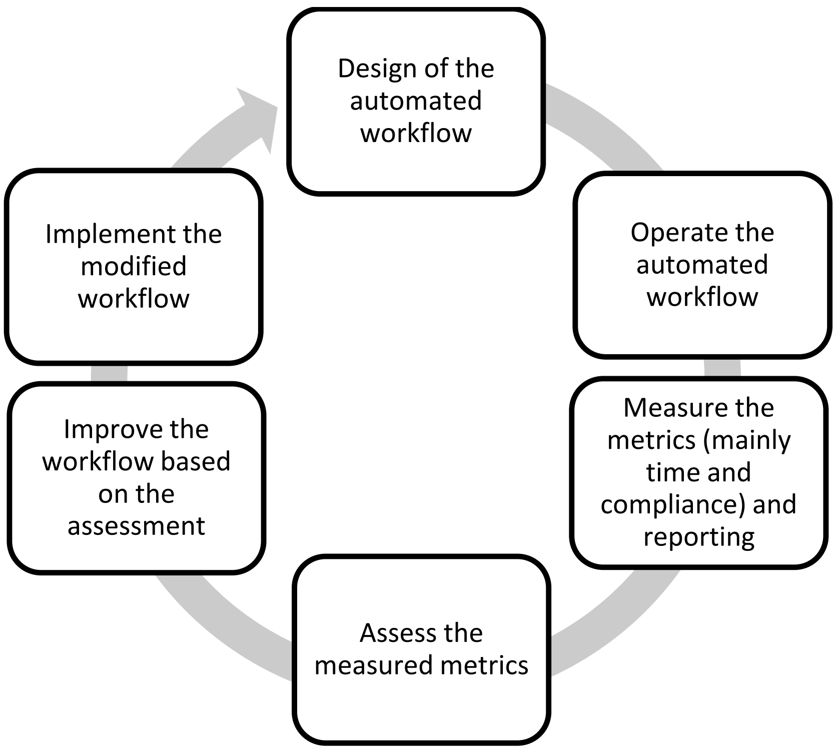


Figure 3-2: Continuous Improvement Process Program (CIPP) for a "Generation Three" workflow-based system

3.3 Workflow Terminology

In this Section, in order to better understand the above process steps and bring more consistency throughout this thesis, workflow terminologies; workflow template, workflow implementation, workflow instance, work item or task in workflows, are defined.

3.3.1 The Definition of the Process of the Change Requests

The process of the change requests shows the path of what is intended to happen when a change request is issued. In other words, when a process completed, it clearly should show what tasks or *work items* must be taken to obtain a particular end.

3.3.2 Work Item or Task

Defined as a fundamental unit of work, work items or tasks are either human-based or machine-based tasks as shown in Figure 3-3. A workflow includes a logical sequence of these work items or tasks.

3.3.3 Workflow Template or Workflow Model

A workflow template or workflow model is defined as the encapsulation of processes for type of work, like change request. Therefore, a predefined process (or processes) may shape the basic structure of workflow template. A snapshot of a change request workflow template is shown in Figure 3-3. In this figure the red circles show that a template includes all tasks; both machine-based tasks and human-based tasks, involved in the process.

3.3.4 Workflow Implementation

A workflow implementation is a workflow template which is customized for a specific activity. With the aim of continuous improvement in the use of a workflow, the modification of the existing workflow implementation, based on its failure identified after workflow implementation's operation for a period of time, may result in a new workflow implementation or a new customized workflow template. Figure 3-4 shows a "new workflow implementation (b)" modified from an "old workflow implementation (a)" due to the two machine-based tasks added. Likewise, Appendices G1 to G8 include all eight workflow implementations with the new tasks added and circled in red in each new workflow implementation compared to its preceding one. These workflow implementations were used in a Canadian oil and gas megaproject, selected as the case study in this thesis.

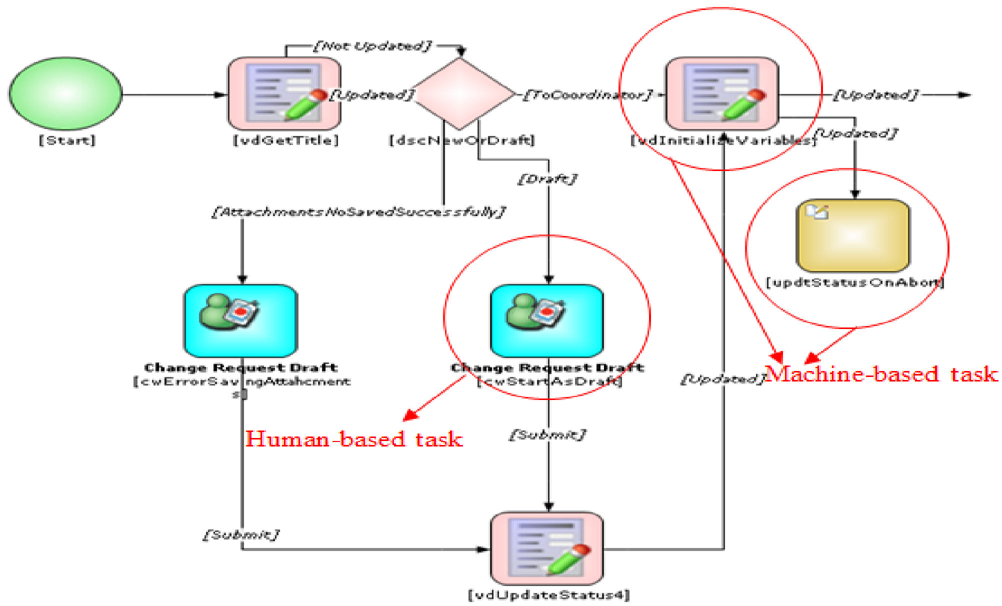


Figure 3-3: Snapshot of a workflow template (courtesy of Coreworx)

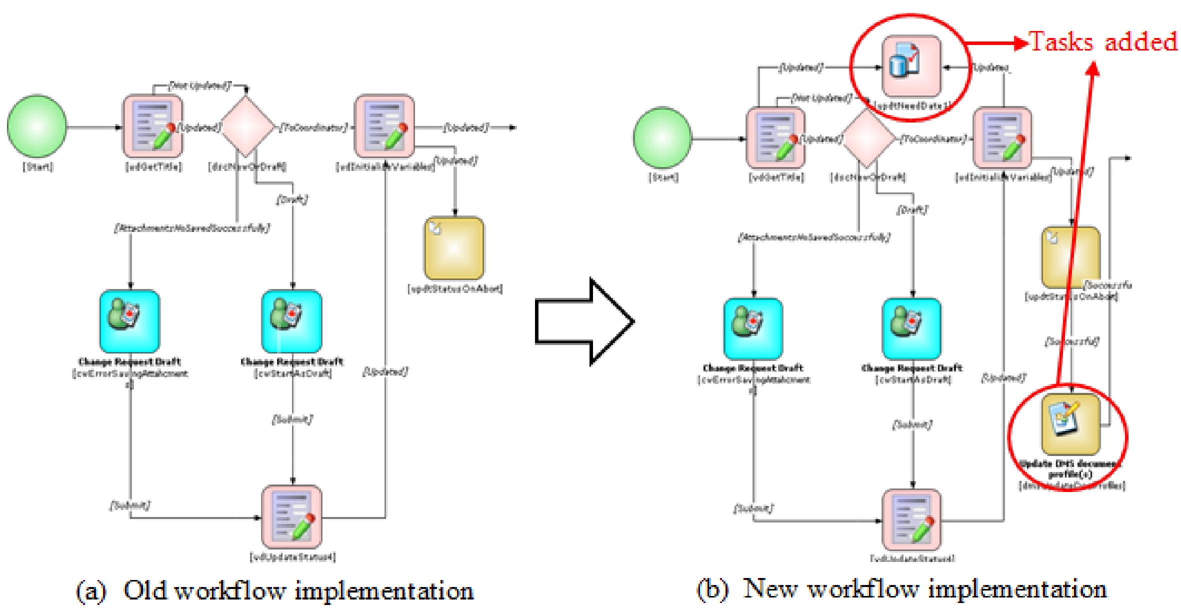


Figure 3-4: Modification of an old workflow implementation (a) to a new workflow implementation (b) by adding two new machine-based tasks

It is important to understand that shifting from an old workflow implementation to a new one does not mean that the old workflow implementation has stopped, and then the new one started. Simply put, the execution of the new workflow implementation may overlap the old one, while still in operation, but not necessarily override it. Considering this, the change requests initiated in the old workflow implementation would be staying in the old one and not being shifted to the new workflow implementation, should the two workflow implementations overlap each other. Figure 3-5 graphically and conceptually shows the behavior of the workflow implementations for a change request workflow for one megaproject. In this figure, the red dots represent the change requests or workflow instances (see 3.3.5) initiated in each workflow implementation, and the arrows represent the time length of the workflow implementations. The red and blue broken lines respectively represent the start and end points of a workflow implementation in the workflow timeline. As seen for instance, the workflow implementation 5 has started after the workflow implementation 4 but has finished before it.

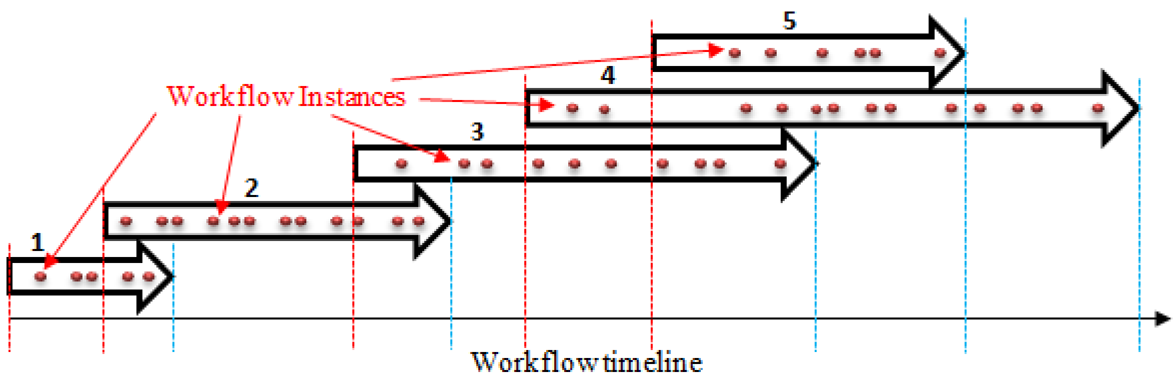


Figure 3-5: Workflow implementations' overlap for a typical megaproject

3.3.5 Workflow Instances

A workflow instance is an executed workflow implementation for an activity. A workflow instance happens when, for example, a change request is initiated, evaluated in some of the work items or tasks, and finally completed (either rejected or approved) in that workflow implementation. Even the incomplete change requests (abandoned at some work item or task) still trigger the implemented workflow's execution. In brief, each execution of a particular workflow implementation due to a change request, as an activity, is considered as a workflow instance of the same workflow implementation. The red dots in Figure 3-5 represent the workflow instances.

3.3.6 Workflow Users

Workflow users are the project team members who, based on the level of their authority, take proper actions (evaluation, verification, approval, or rejection) on a change request when arriving to a particular task (work item) defined in a workflow implementation.

Along with the above workflow terms is the definition of workflow engine which is explained in Section 2.4. Figure 3-6 depicts the *continuous improvement process program cycle* for the change request workflow. The "yes" condition in the decision point of the cycle depends on having enough workflow instances and information showing the failure(s) of the workflow implementation otherwise more workflow instances will be required.

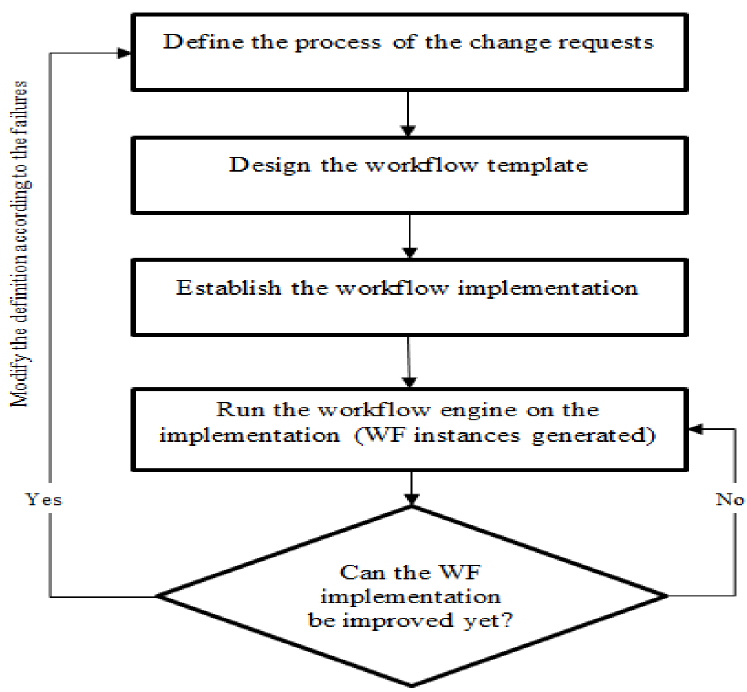


Figure 3-6: Continuous improvement process for the workflow of change request

3.4 The Relation between Change Request, Request For Information (RFI), and Project Change Notice Processes

In Section 2.2.8, it was stated that Change Request along with Request For Information (RFI) and Project Change Notice (PCN), included in a megaproject's Management Of Change (MOC) plan, each have their own process and tasks. Although this research's focus is not the PCN's and RFI's workflow processes, it is worth mentioning how their processes are related to the Change Request's.

As Figure 3-7 (next page) illustrates, the process of a change request can be initiated with no dependency on the process of RFI. Also, not all RFIs trigger the change request process. However, the connection between the processes of the change request and the Project Change Notice (PCN) is different, since only approved change requests, based on which change will happen in the process of the project, will lead to the PCN process. RFI logs or Change logs (the end points of the RFI and Change Request processes in Figure 3-7) represent *storage* where all the details of all RFI and all changes such as the status or origin of an RFI or a change are recorded. This storage can be a proper notebook in Generation One, a spreadsheet in Generation Two, and a database in Generation Three of Change Management process. Therefore, considering the end points in Figure 3-7, it should be emphasized that in each task of the process the status of RFIs or changes are being updated. Manually updating a change log in Generation One and Two is prone to human error, such as typos, wrong date and time stamps or missing date and time stamps, which in turn can be confusing and misleading for the other project team members who may later refer to the logs. This may also result in rework in the project or process. It can be argued that a Generation Three workflow-based process eliminates these errors; hence it minimizes the rate of rework which leads to a time saving in the process as a result. In brief, the above point is related to the compliance benefits of an automated workflow based process, like the Generation Three. Compliance along with other metrics and how to measure them are explained in next Section.

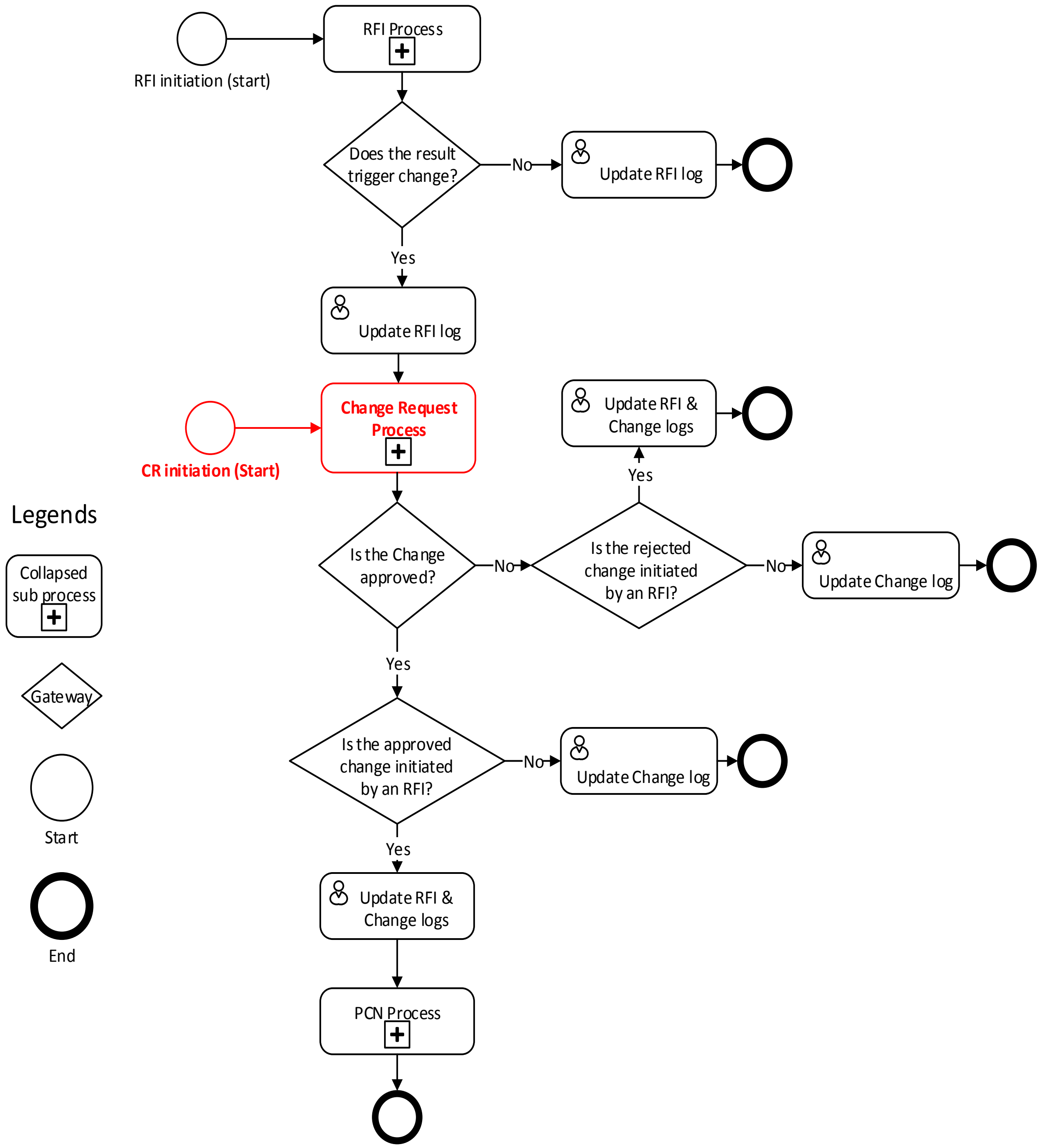


Figure 3-7: the relation between RFI, CR, and PCN's workflows and processes

3.5 Metrics and Measurements

The measures or metrics taken in the change management process must be first meaningful and second justify the business goals, cost, service availability, and reliability (CII, 1994). The Construction Industry Institute (CII, 1994, p: 19) defines "metric" as "*a measurable outcome that indicates degree of success in achieving some quality objective"*. There exist five criteria by which a metric is considered an effective metric. These criteria are: measurability, significance, influence, repeatability, and timeliness defined in detail as follows (CII, 1994):

- *Measurability:* with the assistance of metrics, project team members must be able to determine what a change is, to distinguish between a beneficial and a detrimental change, and to encourage beneficial change and to discourage detrimental change. An up-front agreement, established using a baseline scope, is essential to any metrics system for change management since without this upfront agreement the established metrics will likely fail the measurability criterion.
- *Significance:* a significant metric can be defined as the one that deals with a "key results area". For example, an end user's or an owner's desire of a facility may be its economical operation and its low cost and ahead of schedule delivery. As simple as this desire may seem yet it brings about different ideas from each individual of the project team on how to achieve this. Considering this, before establishing metrics for change management, the project team members should deem how accommodating and helpful a particular metric will be to meet the desires of the end user. Should the metric not serve this end, it is not significant and must be eliminated.
- *Influence:* if any rework has happened in a project, to influence the project, the cause of the rework needs to be measured. If not, management actions may be directed at the wrong cause. That is to say that in change management it is common to collect "effects" data

without the accompanying "cause" data. This makes it difficult for a metric to meet the criteria of influence.

- *Repeatability:* there are three reasons that cause failure of metrics in change management. The first is the lack of an appropriate or well established system for recording or reporting. The second is that the project team members are not familiar with the established system therefore they would not use it. The third is related to the lack of an up-front baseline agreement or communication on what constitutes a change amongst team members. Due to these factors, metrics in change management are often not useful, because they are not consistently repeatable. Significant effort is required for establishing and communicating a baseline agreement regarding the definition of change and the systems to be used in capturing data regarding change.
- *Timeliness:* The purpose of metrics in change management is to enable project management to take action. Hence, it is critical for the management to receive data in a timely manner in order either implement or reject the change. Without this timeliness, an inappropriate level of management may make decisions regarding changes.

Considering the characteristics of metrics, the author of this thesis defined several metrics to meet the main objectives of the research. Table 3-2 represents how the metrics were collected and measured. The metrics are:

- Workflow instances duration reduction in terms of average duration and variance in duration
- User's compliance in terms of change requests' rework and in terms of "clean" response percentage (the clean response means a response before the "respond by" due date)
- Workflow instances' (change requests) traceability

- Incomplete workflow instances (the instances that have not reached to the approval or rejection and abandoned in a task)
- Steady state of the workflow implementation (based on the life cycle of workflow implementation and the number of instances in each workflow implementation respectively)
- Users' Accuracy (for example typos while the user is manually entering the data in the change logs) human mistakes leading to ambiguity for others and rework as a result.

To capture the behavior of different generations of change requests workflows where the above metrics become important, the development of a simulation model for the change request process is a must. The next Section covers this approach.

3.6 The Use of Discrete Event Simulation (DES) to Develop a Simulation Model of the Change Request Workflow

Section 2.11 covered the significance of simulation and more specifically discrete event simulation in the construction industry. The kernel of the following subsections is why discrete event simulation is selected for this research, how it is used to create a simulation model, and introduction of Simul8^{TM} as the selected simulation tool.

3.6.1 Why Discrete-Event Simulation (Simulatibility of the Change Request Workflow)

Banks et al (2009, p: 03) defines simulation as "*the imitation of the operation of a real-world process or system over time*". Simulation processes or systems can be categorized as *discrete* or *continuous, stochastic* or *deterministic, static* or *dynamic* (Banks et al, 2009; Kelton et al, 2002). In the *continuous* systems, the state variable(s) may change continuously over time. A good example of continuous simulation system can be the continuous variation, albeit for a limited-time, of water level behind a dam due to rain storm. In the *discrete* systems, the state variable(s) may change only at a discrete set of points in time. A good example for discrete simulation system is the number of customers in the bank because its change depends on the time when a customer arrives to the bank or when a customer leaves the bank because the service is completed (Banks et al, 2009; Kelton et al 2002). *Deterministic* simulation systems have no random variables like the scheduled arrivals of the patients at a doctor's office whereas *stochastic* systems have one or more random variables like the random arrival times of the customers to the bank or random service times of the tellers. If a simulation system, like a bank hours from 9:00 to 5:00, change over time, it is called *Dynamic*. *Static* simulation systems represent a system at a particular point of time (Banks et al, 2009; Kelton et al 2002).

Based on the simulation definition and different types of simulation systems, a change request workflow can utilize simulation because:

- A change request workflow is an activity that includes a process within a time frame from initiation to completion, therefore it is simulatable.
- A simulation model for a change request workflow will be a discrete stochastic dynamic model since, like the bank example explained above the number of the change requests, as the state variable, changes when a new change request arrives to the workflow or the task on an existing one is completed.

Banks et al (2009) state that simulation is often used for the analysis of the *queuing model*, the key elements of which are the customers which refers to people, e-mail, trucks or any type of entity that demands a service from a system and servers which refers to receptionists, computer, loaders or any resource that provides the demanded service. Therefore, in a change request workflow, the Engineering, Vendor, Contract, and Field change requests are the customers and the work items or tasks to be done on these change requests in the process are the servers.

The *calling population*¸ defined as *"the population of potential customers"* (Banks et al, 2009, p: 229) for change requests is treated as essentially *infinite* because as many change requests as necessitated can be initiated in the change request workflow in the project life cycle. The *capacity* of a change request workflow is treated as *unlimited* because *all* generated change requests join a queue or waiting line before a particular server (a task or work item) to be served.

The arrivals of change requests, either one at a time or in batches (constant or random size), occur at either scheduled times or random times. The constant-sized batch scheduled arrival of change requests is common in "Generation One" of change management. Due to the physical distance between a contractor and owners office, for instance, the change requests are collected and will be sent for evaluation when the batch reaches to a certain number, for example 20, or twice a week no matter what size the batch is. This is covered in more detail in Chapter 6. It is sufficient to say that the more the change request process shifts to "Generation Two" and "Generation Three", the less batch delivery of change requests in a scheduled time exists. This is due to use of the Internet and computers in "Generation Two" and "Generation Three".

For the change requests with random arrivals, the arrival model follows the *Poisson arrival process* and the inter-arrival times (the time between the arrival of change request *n – 1* and change request *n* is *exponentially distributed*. This arrival behavior of change requests is estimated in detail in Section 4.6.

In simulation, the common *Queue disciplines*, defined as *"the logical ordering of customers in a queue and the determination of which customer will be chosen for service"* (Banks et al, 2009, p: 233) are First-In-First-Out (FIFO), Last-In-First-Out (LIFO), Service in Random Order (SIRO), Shortest Processing Time (SPT), and Service according to Priority (PR). The queue discipline for the change request workflow follows a special form of FIFO, because the change requests sequentially arrive in the workflow but due to discrepant-length service times (the time a task on a change request take) they do not necessarily leave it in the same sequence (Banks et al, 2009). This special format is called First-In-Random-Out (FIRO) in this thesis. This behavior is explained in detail in Section 4.4.1.

The servers can be single servers (c=1), multiple server ($1 < c < \infty$), or unlimited servers ($c = \infty$) (Banks et al, 2009). In the change request workflow, the tasks or work items (servers) are often multiple servers because the number of the project team members assigned to a particular task varies. These project team members who are assigned to a task can work in parallel when more than one change request arrives to that particular task and at least one project team member is found busy.

Considering the above characteristics; the calling population, the system capacity, the multiple servers, the queue discipline, and the arrival process of the change request workflow, the simulation model of change request workflow, based on "*A/B/c/N/K queuing notation*" (Kendall 1953 cited in Banks et al 2009), is $M/G/c/\infty/\infty$ where:

M: represents exponential distribution for inter-arrival times

G: represents general/arbitrary distribution for service times

c: represents the number of parallel tasks (servers) ($1 \leq c \leq 8$)

∞: represents the unlimited queue capacity for change requests arriving to tasks (servers)

∞: represents the infinite population of change requests potential arrivals.

3.6.2 How to Use Discrete-Event Simulation to Simulate the Change Request Workflow

Discrete event simulation, as a prediction tool, can be used to design a simulation model for the change request workflow. This essentially demands proper data from the past to the present of the workflow since it helps to capture the behavior of the workflow. This proper data is concerned with the arrivals times of the change requests to each task of the workflow from initiation to completion, the time distribution of tasks or service times respectively, and the number of project team members assigned to each tasks. In parallel with collecting the above data, the model of the workflow should be conceptualized (Banks et al 2009). This means that the essential features of the workflows, such as human-based tasks due to their impact on simulation results, should be identified and basic assumptions characterizing the conceptual model should be selected and modified (Banks et al, 2009).

The model conceptualization can be started with a simple model and then developed to a complex one. A one-to-one mapping between the model and real system is not only unnecessary but also often times confusing therefore the essence of the real system is required (Banks et al, 2009). These principles are followed in the development of the change request workflow simulation model as explained in Chapter 4.

The model translation or the merge of the simulation model and the data collection should happen in an environment where a great deal of information storage and computation is required (Banks et al, 2009). Simul8™, a simulation software application, provides such environment. The introduction of Simul8™ and it advantages over other simulation software applications such as Arena™ and EZStrobe™ is covered in the next Section.

To see if the simulation model of the change request workflow in Simul8™ environment performs as properly as does the real change request, it needs to be verified and validated. Verification pertains to correctly representing input parameters and logical structure of the model in the simulation environment. Validation is pertinent to the calibration of the simulation model or comparing it against the actual system behavior in an iterative process up to an acceptable level of accuracy (Banks et al, 2009). Both verification and validation of the change request workflow is explained in detail in Chapter 5.

Considering the model is validated, in the experimental design the length of simulation runs, the number of replications, and the confidence limits should be calculated. The analysis of the number of runs enables the analyst to determine for the more runs. Before the implementation of the model, the results of the runs and details of the analysis need to be documented (Banks et al, 2009). This approach for the change request workflow is covered in Chapter 6.

3.6.3 Simul8™ Introduction

To develop the change request workflow simulation model, Simul8™, as one of the most known and powerful simulation tools, was considered. Although there are other simulation tools such as EZStrobe™, which is mainly tailored to simulate the cyclical behavior of the activities around the construction sites, or Arena™, which is used for manufacturing, the author's decision to use Simul8™ was due to comparative analysis made possible through a graduate course in which the author of this thesis learned Simul8™ along with the various built-in functions and programming environment of Simul8™.

Table 3-1 shows a comparison between Simul8™, Arena™, and EZStrobe™ simulation tools. The content of the table is compiled based on the author's practical experience with the aforesaid simulation software packages and studying their vendors' websites and Chapter 4 of Discrete-Event Simulation text book (5th edition) by Banks et al in addition to interviewing two simulation experts. It was then concluded that Simul8 best fit the author's capabilities and the needs of the research.

Table 3-1: A comparison amongst three selected simulation tools (Simul8/Arena/EZStrobe)

Features	Simul8	Arena	EZStrobe
Built-in Functions	Various	Various	Limited
Programmability	Yes	Yes	No
User's proficiency level in coding and programming	Basic	Intermediate	N.A.
BPMN Built-in Environment and Visio Compatibility	Yes	No	No
Accessibility to software package and its versions	Free Professional version for Ph.D. Students	Free Basic version for undergrads	Free One version only

3.7 Summary

This Chapter covered the proposed methodology to meet the main objectives of this research. To meet the first objective: *evaluate and quantify the difference in performance between the levels of automation of change management processes*, a comparison between three different generations of change management process, categorized as "Generation One", "Generation Two", and "Generation Three" were required. A clear definition of tasks along with their completion time and the number of project team members and their responsibilities in each task in each generation, ideally all used in one megaproject, was necessary to permit an "apples to apples" comparison. This information, as discussed in detail in Chapter 4, was provided from the database of "Generation Three", manual change logs of "Generation One and Two", and interviews with project experts. For the second main objective, *develop and validate a model for continuous improvement of automated change* *management processes as per defined metrics*, continuous improvement process program (CIPP) with six steps; design the automated workflow, operate the automated workflow, measure the metrics defined, assess the automated workflow, improve the automated workflow, and improve the automated workflow, as the proposed methodology, was introduced. This methodology was considered ideal for workflow-based "Generation Three" where the failures of workflow instances in a workflow implementation would be identified when the workflow implementation had been in operation for a while, thus a sufficient number of instances were generated. A new workflow implementation, as the improved model of the old workflow implementation where the failures by adding or deleting work items or tasks were rectified, comes into operation. Workflow implementation, workflow instances, workflow template, work item or task, and workflow user were explained as a set of standard definitions of workflow terminology in order to bring better consistency throughout this thesis. Also, based on significance, influence, timeliness, repeatability, and measurability as five criteria for effective metrics; (1) workflow instances duration reduction, (2) user's compliance in terms of rework and in-time response, (3) incomplete workflow instances, (4) steady state of the workflow implementation, and (5) user's accuracy were defined as the metrics for workflow implementations comparison.

Since the change request workflow has a process-based approach happening in a time frame, it can be simulated. The simulation model of the change request workflow, as discussed, was defined as a discrete-dynamic-stochastic simulation model. Model conceptualization and data collection from the real change request workflow were the first requirements of the change simulation model. Simul8^{TM,} the selected simulation software package proved to enjoy the proper simulation environment where the model conceptualization and data collection could be merged as the model translation. The verification and the validation of the simulation model, as to be discussed in Chapter

5, were introduced. The next Chapter discusses how data was collected to calculate the metrics and address the research objectives.

Table 3-2: Metrics, how to collect and measure them

Objectives	Measure of Success and Metrics	How to collect (with an EPPMS)	How to measure	Timeliness	
				Leading Indicators	Lagging Indicators
More efficient and effective management of CRs	Workflow instance duration reduction.	• Compare the average duration of workflow instances in three levels of change management processes. • Compare the average duration of instances in the workflow implementations	• Consider the date and the time stamps recorded in the database and also the change logs for the change requests • Survey the project team members to estimate the average time in case of unavailability of the date and time stamps.	Leading	
	User's compliance	• Compare the number of change requests' rework	• Consider the number of times a change request is stamped "rework" in the database and change logs. • Survey the project team to estimate the number of times a change request is resent due to incomplete status (emails with missing attachments)		Lagging
	Traceability	• Compare the database history and change logs for each implementation	• Consider the trace of change requests in a workflow for the location and the time stamps.		lagging
	Steady state of the workflows	• Compare each workflow implementations' life cycle	• Consider the life cycle duration and the number of instances in each workflow implementation.		lagging
	User's accuracy	• Assess the rate of inaccuracy in technical or business specifications in each implementation	• Compare the number of typos, technical errors in the specifications recorded in the database and change logs		lagging

Chapter 4
Data Collection

This Chapter introduces a Canadian oil and gas megaproject selected as the case study of the research for data collection and data analysis. The challenges and the strategies for overcoming the challenges regarding the change request workflow and the simulation model are described. The analysis of the input data for the developed simulation model of the change request workflow along with a brief explanation of important commands of Simul8™, the selected simulation software package used to develop the simulation model ends the Chapter.

4.1 A Case Study: Source of Empirical Data

In order to further the research one of the Canadian oil and gas megaprojects in which Coreworx™ the partner in this research has been involved, was considered. The following three sub-Sections respectively cover this case study introduction and the interviews conducted with project experts followed by data extraction from Coreworx™'s database.

4.1.1 The Case Study Introduction

The case study under consideration is a Canadian oil and gas megaproject located in the west coast area of Canada. Coreworx™'s automated workflow-based change management process software package, which represented a "Generation Three" change management process, was in use to handle the potential change requests from initiation to completion. The importance of this project, as the case study in this research was from this perspective that prior to executing Coreworx™'s automated workflow-based change management process package, the project had used a combination of "Generation One" and "Generation Two" processes to record the change requests. This, as assumed before, was ideal since it provided an 'apples to apples' comparison between the aforesaid processes. The project was composed of two main Sections, called OGP1 (Oil and Gas Plant) and OGP2 in this research, awarded to one Engineering Procurement Construction (EPC) contractor. As tabulated in Table 4-2 and Table 4-3, 572 and 72 change requests in four types of Engineering, Vendor, Field, and Contract, were executed in OGP1 and OGP2 respectively.

4.1.2 Interviews with the Project Experts

Interviews, regardless of their *unstructured, semi-structured, or structured* forms (Ellram, 1996; Gugiu & Rodriguez-Campus, 2007) play a vital role in a case study research. According to Yin (2008) interviews are one of most important sources of information and as Knight & Ruddock (2008) state they are used to fully understand *the informant* impressions or experiences or to learn more about their answers to questions. For the aforesaid project one in-person face-to-face official interview with the business analyst of the project was conducted in Calgary Canada. Following this, in order to clear ambiguity and uncertainty around the data analysis, the author of this thesis made more than 10 teleconference interviews with the business analyst and the project coordinator.

4.1.3 Data Extracted from the Vendor's Database

With the official permission of the project's and Coreworx™'s executives and abiding by the data confidentiality, the author of this research was allowed to extract the proper empirical data required to develop the simulation model of the change request workflow (explained later in this Chapter and Chapter 5) from Coreworx™'s database. The data was composed of a couple of tables in which the codes, activities, staff, status, and the time stamps all concerned with different types of Change Request Documents of the workflow were recorded. Table 4-1 shows the structure of the database table. The description of the database table's columns is as follows:

- *Change Type:* this column records the types of change request document. There exist four different types of change request documents; Contract Change Request (CCR), Engineering Change Request (ECR), Field Change Request (FCR), and Vendor Change Request (VCR).

- *WF_ID (Workflow_ID):* in this column a unique number is given to each change request workflow instance upon entering into the workflow implementation. Each workflow instance takes a code composed of letters and numbers as the "Document ID" used to classify that particular document.
- *Activity Display Name:* this column represents all the tasks (work items) of the Change Request workflow implementation in which a change request document is received, evaluated, and sent on. It represents what type of task the assigned project team member is required to do on an arriving change request document.
- *Created Date Time:* this column records a time stamp, based on the date and time (HH:MM:SS:MS) given to a change request document upon its arrival to a specific task. This is the date and time when a document has reached a particular task of the change request workflow implementation for evaluation.
- *Ownership Date Time:* this column records a time stamp, based on the date and time (HH:MM:SS:MS) given to a change request document when a project team member first opens it to take the predefined action in a specific task.
- *Completed Date Time:* this column records a time stamp, based on the date and time (HH:MM:SS:MS) given to a change request document when a project team member sends it onward from a specific task.
- *Respond By:* this column includes the date and time before when the assigned project team member should take the defined action on the change request document arriving at a

particular task. As the workflow data indicates, the project team member receives a warning should they miss the due date and time set in the 'Respond By' column.

- *Name:* this column includes the names and surnames of the project team members responsible to take the defined action on a change request document in a particular task.

- *Current Status:* this column indicates the real time status of a change request document in each task.

- *Version:* this column indicates a number representing in which workflow implementation the change request document has been executed.

Table 4-1: The Structure of the Change Workflow Database table Illustrated with Examples

Change Type	WF_ID	Activity Display Name	Created Date Time	Ownership Date Time	Completed Date Time	Response By	Name	Current Status	Version
VCR	10	Review (Engineer)	Wed 4/13/11 18:53:46	Sat 4/16/11 23:00:01	NULL	Sat 4/16/11 23:00:00	xx	Send For Review	3
ECR	65	Approve (Approver)	Sat 4/16/11 23:00:02	Mon 4/25/11 18:30:23	Mon 4/25/11 18:33:39	NULL	xx	Approved	6
FCR	1017	Change Request Participants Verification	Mon 4/25/11 18:33:39	Mon 4/25/11 18:34:03	Mon 4/25/11 18:34:10	NULL	xx	Send On	7

The database analysis showed that there were over 16000 rows for OGP1 and near 1800 rows for OGP2 of the aforesaid project recorded in the table of the database. In each row, the information concerned with a change request workflow instances document activity was captured. Many rows may be related to one instance. The number of workflow instances (change request documents) was 572 in all 8 versions (workflow implementations) in OGP1 and 72 in OGP2. Table 4-2 and Table 4-3 show the details of the number of workflow instances based on the type of change requests in all 8 versions (implementations) of the workflow. According to the time stamps of the change request documents it is important to note that both OGP1 and OGP2 were being executed in parallel almost in the same timeline, and hence one change request workflow template with 8 workflow implementations were used to manage the change requests. However, the time period for each workflow implementation was not the same in both OGP1 and OGP2. This point in detail is explained in Chapter 6 on the output data analysis.

Table 4-2: Number of workflow instances based on types of change request in each version (workflow implementation) in OGP1

Types of Change Request (CR)	Versions (Workflow Implementations)								Total
	1	2	3	4	5	6	7	8	
Engineering CR	1	6	14	7	4	15	9	2	58
Vendor CR	3	3	33	11	6	35	34	3	128
Field CR	0	13	57	22	9	73	90	17	281
Contract CR	0	8	16	15	0	39	20	7	105
Total	4	30	120	55	19	162	153	29	572

Table 4-3: Number of workflow instances based on types of change request in each version (workflow implementation) in OGP2

Types of Change Request (CR)	Versions (Workflow Implementations)								Total
	1	2	3	4	5	6	7	8	
Engineering CR	0	0	0	1	1	16	23	0	41
Vendor CR	0	0	3	0	2	10	8	3	26
Field CR	0	0	0	0	0	0	2	0	2
Contract CR	0	0	0	0	0	3	0	0	3
Total	0	0	3	1	3	29	33	3	72

The number of workflow instances in each version (workflow implementation) in both tables, when compared, indicates that change request automated workflow has been by far more active in

OGP1 than OGP2. This can pertain to this point that, according to the analysis of the project documents and interviews with the project experts, OGP1 started almost one year earlier and finished almost 6 months earlier than OGP2. Also, the plan of both Sections, according to their blueprints, was up to 85% identical. Thus, the factors leading to initiating change requests in OGP1 were not repeated in OGP2, and as a result the number of change requests in the latter became less than that in the former. This can also be a good example of "*continuously improve from lessons learned"*, the 5th step of CII's effective change management explained in Section 2.7.

The workflow instances in OGP2 were used to develop the simulation model of the change request workflow in Simul8™, and those in OGP1 were used to analyze the continuous improvement process in the workflow implementations. The use of Simul8™ and model conceptualization for the change request workflow was discussed in Section 3.6 in Chapter 3. In this Section, two important types of input data; arrival times of the change requests and service time of the tasks (work items) were outlined. The next Section's focus is on importance of waiting time of change requests in a queue and nominal working time of tasks.

4.2 Significance of 'Waiting Time' and 'Nominal Working Time' for the Simulation Model

When it comes to model conceptualization, as Banks et al (2009) state, comprehension of the essence of the real system is required. Keeping this principle in mind, those details with significant effects on the behavior of the change request workflow were contemplated. The workflow was composed of two main types of tasks; the human-based (manual) tasks and machine-based (invoked applications) tasks. The whole time of a workflow instance broke down into two parts: 'Waiting Time' (idle time) and 'Nominal Working Time' defined as follows:

- *Waiting Time:* this is the difference between the time when a change request document has arrived at a task (work item) and the time when a project team member assigned to that task starts to work on it. According to the database Table 4-1:

$$Waiting\ Time = Ownership\ Date\ Time - Created\ Date\ Time$$

- *Nominal Working Time:* this is the difference between the time when a project team member assigned to a task starts to work on the existing change request document (opens the change request document) and when he/she is through with the change request document and sends it on to the next task. According to the database Table 4-1:

$$Nominal\ Working\ Time = Completed\ Date\ Time - Ownership\ Date\ Time$$

In a Discrete-Event Simulation (DES) process, a queue occurs when an entity (customer) arrives at the activity centre, but the activity centre is either busy with the existing entity, or the resource (user) assigned to that activity centre is not available. Therefore, in the change request workflow process, queue and waiting time happen in the human-based (manual) tasks where the busyness or the availability of a project team member (resource) in those tasks matters. Effectively there is no waiting time or queues in the machine-based tasks. Analysis of the data confirmed that the machine-based tasks would take not more than a couple of seconds to complete, hence there would be no queue (waiting time) whereas the nominal working time of the human-based tasks and their queues (waiting time) would vary substantially in each task (work item). Considering this, the simulation model of the change request workflow only contains the manual tasks where the waiting and effective working times take significance. The next Section describes the change request workflow model conceptualization and its iconography.

4.3 Iconography and Description of the Change Request Workflow Model Conceptualization

Model conceptualization of the change request workflow, as stated before, is composed of the essential elements of the real change request workflow. The focus of the following subsections is on the description of this model and its iconography.

4.3.1 Change Request Workflow Model Conceptualization

Coreworx^{TM}'s change request workflow implementations were carefully observed. Based on this observation, the essential tasks (work items), including all human-based tasks and machine-based gateways, were selected. Then the conceptual model of the change request workflow was designed accordingly (Figure 4-1). This conceptual model was the basis for the simulation model of the change request workflow developed in Simul8^{TM} (see Figure 4-10). Appendix G1 to G8 include all eight workflow implementations used for the project under consideration. A point of interest is that in all these workflow implementations the process and the human-based tasks remained intact and some machine-based tasks were either added or deleted in the succeeding implementations in order to facilitate the process. This also means that the model illustrated in Figure 4-1, retains its structure through simulation of all implementations. The addition or deletion of these machine-based tasks is shown in red circles in each new workflow implementation (appendices G1 to G8) compared to its preceding one. Also Figure 3-4 in Chapter 3 illustrates two snapshots of an old and a new workflow implementation where in the latter two machine-based tasks are added.

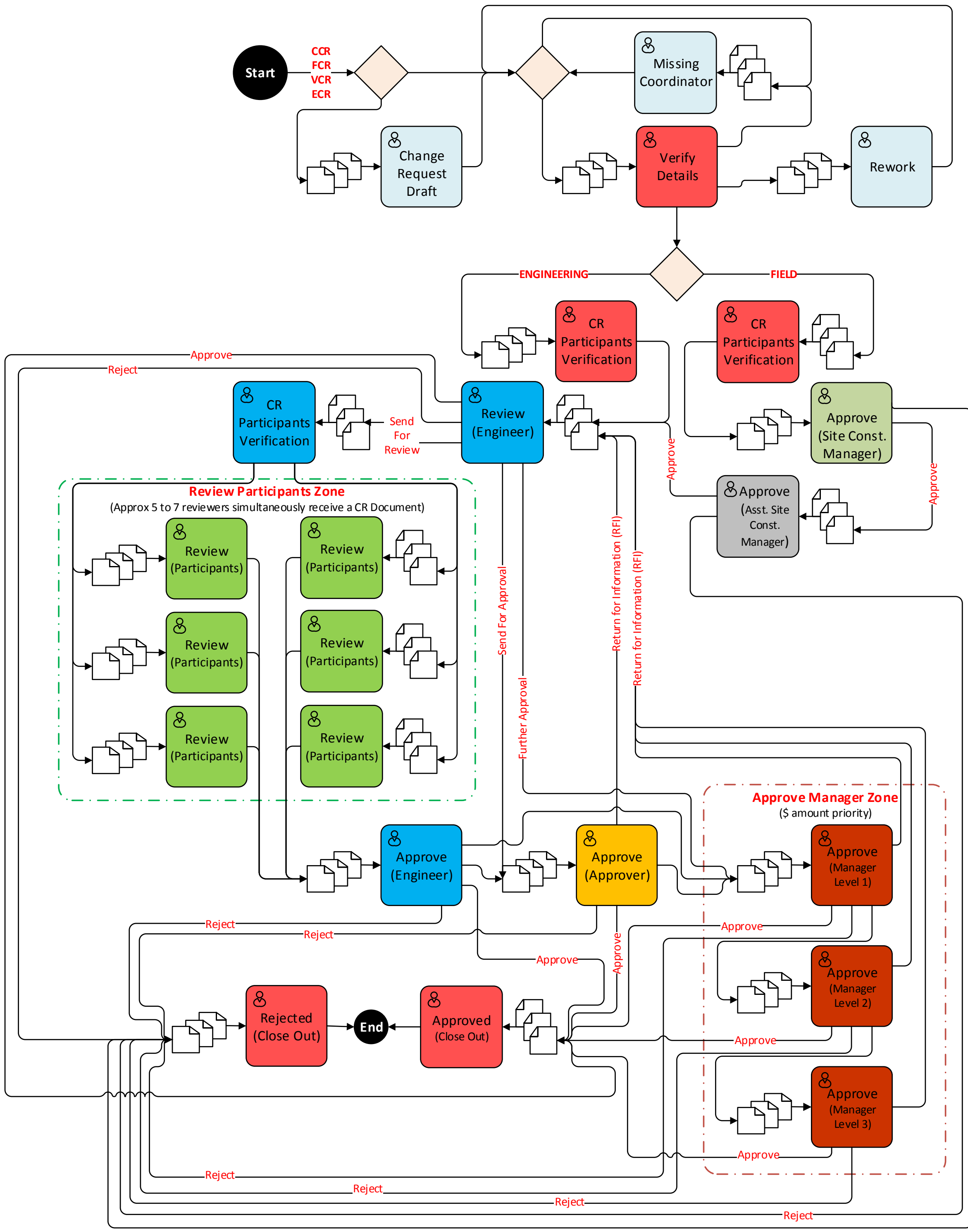
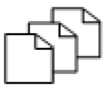
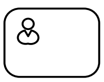
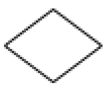
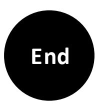


Figure 4-1: the Change request workflow conceptualized model used for the development of the simulation model

4.3.2 Iconography of the Model

The icons, used in the above model and their description are tabulated as follows:

Table 4-4: The iconography and the description of the change request workflow model in Figure 4-1

Icon	Description
	The initiating point of one of the change requests; Engineering, Vendor, Field, Contract Change Requests (ECR,VCR, FCR, and CCR)
	Represents the queue of the change requests waiting for a project team member to do defined task. Upon arriving at this point, a CR receives a “created date time” stamp.
	Represents the task the project team member does on the delivered change request. Upon entering in and exiting from this point, the change request gets “ownership date time” and “completed date time” stamps respectively.
	Represents a “gateway” directing the change request in the determined directions based on the decision made by the project team member. Gateways are machine-based tasks so the waiting time and nominal working time are considered zero.
	Shows the sequence of change request flow.
	The point where the change request, either rejected or approved, is closed.

4.3.3 The Description of the Change Request Workflow Model Conceptualization

As shown in Figure 4-1, the issuance of a change request (CR), as an Engineering, Vendor, Field, or Contract, is the inception of the workflow execution. The cause of a change request can be (or cannot be) a Request For Information (RFI) coming from the RFI workflow (see 3.4 and Figure 3-7: the relation between RFI, CR, and PCN’s workflows and processes If the initial draft of the CR requires modification, it first goes to “Change Request Draft” and then goes for “Verify Details”, otherwise it directly moves on to “Verify Details”. The incomplete CRs are sent back to “Rework” for modification and completion. Unless the CR is complete in terms of sufficient information about that particular change, the loop between “Verify Details” and “Rework” may continue. The change requests related to Engineering or Vendors (ECRs and VCRs) take the “Engineering” path and those related to Field and Contract take the “Field” path. This procedure simply distinguishes the types of CRs from each other and directs them towards the next tasks. Engineering and Vendor change requests (ECRs and VCRs) directly go to “Review (Engineer)” while the Contract and Field change requests (CCRs and FCRs) first go to “Approve (Site Construction Manager)” then to “Approve (assistant Site Construction Manager)” and then, providing that the CR is approved in both tasks, the CCRs and FCRs join the ECRs and VCRs in the “Review (Engineer)”. As Figure 4-1 depicts the CR goes directly to “Rejected Close Out”, should the project team member in “Approve (Site Construction Manager)”, “Approve (assistant Site Construction Manager)”, or “Review (Engineer)” reject the CR. The engineer responsible to review the CR in the “Review (Engineer)” can directly reject or approve the CR. If the approved CR requires further review the same review engineer shall verify the reviewers in the “CR Participants Verification” task and then send the CR to “Review Participants” where the CR fans out to the selected participants who will receive that particular CR simultaneously. Depending on the type of the CRs and also the decision made by the review engineer, the number of participants varies, but as the data analysis shows it is between 5 to7 (this number is also confirmed by the project expert during the interview). The CR will not be sent on to the “Approve Engineer” (usually the same person as “Review (Engineer)” unless all the participants in the “Review (Participants)” have responded and sent the CR. In other words, no matter how fast one participant sends the CR to the approve engineer, the system awaits the last participant’s response. Based on the “review participants” evaluation, the “approve (engineer)” can either reject, in which case the CR directly goes to the “Rejected Close Out”, or approve the CR. If requiring more approval due to its higher dollar amount, the CR shall be sent to the “Approve (approver)” otherwise it directly goes to the “approved close out”. The CR in this task can be either rejected, approved or sent for further approval to “Approve Manager Zone” where “Approve (Managers level 1, 2, and 3)” receive the CR respectively (see Figure 4-1). The cost impact of the CR determines whether or not it must be sent to higher managerial levels. That is to say, the higher is the cost impact, the higher manager is required to decide on the approval or rejection for the CR. In the project under consideration, lead engineer was defined as the “approve (manager level 1)”, project manager as “Approve (manager level 2)”, and project director as “Approve (manager level 3)”.

The color coding in the workflow Figure 4-1 represents that in those tasks colored alike, the role and also the project team member remain the same. For instance, the CR that has been verified in “Verify Details” by person “A” (role: *coordinator*, project team member: *A*) will be evaluated in “CR Participants Verification” and will be rejected/approved in “Rejected Close Out”/”Approved Close Out” by the same person. That is why, as shown in Figure 4-1, all these tasks are colored in red. By the same token, person “B” may evaluate a CR in “Change Request Draft” and “Rework” so does person “C” in “Review Engineer”, “CR Participants Verification”, and “Approve Engineer”.

This color coding does not apply to “Review Participants Zone” (Shown as a green broken-dotted-line box in Figure 4-1 and “Approve Manager Zone” (Shown as a dark red broken-dotted-line box in Figure 4-1) because for the “Review Participants” as mentioned above, there are 5 to 7 different participants and for the “Approve Managers”, the managers cannot be the same due to the difference in their managerial levels. However, managers in higher levels can approve or reject a CR should the lower level manager not be available to do their task or the lower manager, as long as delegated, can sign off a CR on behalf the higher manager. The unavailability of project team members assigned to do a defined task on a CR may lead to the *reassignment* of another project team member to do the task on the CR. For instance, if person “A”, having verified an ECR in “Verify Details”, is not available to approve the same ECR in “Approve Close Out”, person “D” would be reassigned to do the job.

4.4 Challenges in the Development of the Change Request Workflow Simulation Model

4.4.1 "First In Random Out" Behavior of the Workflow

Section 3.6.1 of Chapter three introduced the most common Discrete-Event Simulation (DES) queue disciplines such as First-in-Frist-out (FIFO), First-in-Last-out (FILO), Service in Random Order (SIRO), Shortest Processing Time (SPT), and Service according to Priority (PR) (Banks, et al. 2009). As explained in the following paragraphs, First-in-Random-Out (FIRO), derived from FIFO, best fits the behavior of the change request workflow.

Carefully following the behavior of the workflow instances (change request documents) in the workflow, it was observed that the change requests (CRs) would sequentially take a time stamp upon their arrival to the workflow but would not necessarily be evaluated and sent on in the same sequence. For instance, two CRs (workflow instances) with the workflow ID = 42, 64 were time-stamped as "Fri 5/13/2011 18:11:02" and "Wed 5/25/2011 23:34:58" in "Verify Details" respectively but the user (project team member) in "Approve Engineer" had evaluated and sent on the CR (workflow instance) 64 sooner than 42. This behavior proved that the project team member could freely select any CR that was *not* first in the queue. In brief, the queue discipline can be called *First-In-Random-Out (FIRO)*. Of course this behavior heavily depends on the importance and priority of the CR in the queue. Interestingly, this behavior was seen mostly in the "Review Participants" task where a CR, such as an Engineering CR (ECR) was received simultaneously by 6 reviewers, and after that, for instance a Vendor CR (VCR) was delivered to 5 reviewers, 3 of whom had already received the ECR. The reviewers may have found the VCR more important than the ECR so, they would evaluate and send it on to the "approve engineer" task before the ECR. Therefore, the VCR arriving *after* the ECR to the queue of "review participants" would leave the task *before* the ECR.

A simple analogy to the behavior of the workflow is how individuals respond to their emails. They receive their emails in a sequentially time-stamped manner, but the way they select emails and respond to them is based on the importance of the mail. The same holds true for journal article reviews and many other professional tasks.

It should be noted that the user (project team member) of the change request workflow could distinguish those CRs which were more important or had higher priority than the rest. The system provided the user with *3 color-coded flags*; green, yellow and red to prioritize the CR. Should a user flag up a CR as red, the other users would consider the CR with the highest level of importance and would be prompted to respond to it earlier than the other CRs, flagged with either yellow or green. Considering what is stated above, one of the most challenging parts in simulating the change request workflow, which is successfully done, was the implementation of the logic of this *First In Random Out* behavior in the Simul8 software application, especially between the "review engineer", "review participants" and "approve engineer".

4.4.2 Number of Resources (Project Team Member) in each Workflow Task

In Simul8^{TM} software application, a resource represents an item required at the work centre to work on an entity existing in the work centre. Examples of resources can be laborers or special fitments for machines [http://simul8.com/support, last accessed: Apr 20th 2014]. Based on this definition, the project team members involved in the change request workflow were considered as the resources assigned to a particular workflow task (same as a Simul8^{TM}'s work centre defined above) to work on a CR document (entity) when arriving to that task. The analysis of the project's database indicated that there had been 41 project team members (resources) in the OGP2 to work on the CRs while the change request workflow had been in action. It was also noted that there were some project team members who had been very active in different workflow tasks, while some had worked on only one or two CRs in one task. Therefore, to define these project team members as the resources used in the simulation model, without compromising the simulation model validity, a virtual resource pool, composed of 29 project team members (in OGP2) who had been active in the different workflow implementations (versions), was created (See Figure 4-10 and Figure 4-14). Based on 8 different implementations (versions) of the change request workflow, the number of resources in each workflow work centre of both OGP1 and OGP2 is respectively tabulated in Table 4-5 and Table 4-6.

Table 4-5: Number of project team members (resources) in each workflow task/workflow implementation (OGP1)

No of Project Team Members (Resources) in each Workflow Task	Workflow implementations (Versions)						
	2	**3**	**4**	**5**	**6**	**7**	**8**
CR Draft	3	8	3	3	9	5	5
Verify Details	2	3	2	1	2	2	2
Rework	2	10	5	6	11	9	4
Missing Coordinator	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CR Participant Verification (Field=CW Task4)	2	2	2	2	2	2	2
Approve (Site Construction Manager)	1	2	2	1	3	2	1
Approve (Assistant Const. Manager)	1	1	1	1	1	3	1
CR Participant Verification. (Eng)	2	2	2	1	2	2	2
Review (Engineer)	7	13	7	11	11	10	3
CR Participant. Verification. (Coreworx Task5)	6	13	7	4	12	9	4
Review (No of Participants)	12	21	20	11	29	27	14
Approve (Engineer)	4	10	7	4	12	9	4
Approve (Approver)	2	3	1	1	2	1	1
Approve (Manager Level 1)	1	N/A	N/A	N/A	N/A	N/A	N/A
Approve (Manager Level 2)	1	1	1	N/A	1	1	1
Approve (Manager Level 3)	1	1	N/A	N/A	1	N/A	N/A
Approved Close out	2	2	1	1	2	2	2
Rejected Close out	2	2	2	1	2	2	2

Two points are worth contemplating for these two tables. First, the number of project team members in a particular workflow task (e.g.: CR Draft) changes from one workflow implementation (version) to another. Second, the workflow implementations (versions) 3, 6, and 7 are the busiest in OGP1 and 6 and 7 in OGP2. The empty cells (shown as N/A) in the tables mean that no document has reached to that particular workflow task for evaluation in that workflow implementation. Another important point is concerned with the number of reviewers simultaneously receiving a CR to review in “Review Participants” task. As stated earlier, there are on average 5 to 7 reviewers for a particular CR, whereas in workflow implementations (versions) 6 or 7 of OGP1, for instance, the total number of reviewers is 29 and 27 respectively. These are the numbers of *all* reviewers who have reviewed CRs throughout the operation time of workflow implementations 6 or 7. Some of these reviewers may have received only one CR to evaluate while some have routinely reviewed the CRs in the “Review Participants” task.

Table 4-6: Number of project team members (resources) in each workflow task/workflow implementation (OGP2)

No of Project Team Members (Resources) in each Workflow Task	Workflow implementations (Versions)				
	3	5	6	7	8
CR Draft	1	N/A	3	3	1
Verify Details	1	1	3	3	1
Rework	N/A	2	6	4	N/A
Missing Coordinator	N/A	N/A	N/A	N/A	N/A
CR Participant Verification (Field=CW task4)	N/A	N/A	1	1	N/A
Approve (Site Construction Manager)	N/A	N/A	N/A	1	N/A
Approve (Assistant Const. Manager)	N/A	N/A	1	1	N/A
CR Participant Verification. (Eng)	1	1	3	3	2
Review (Engineer)	1	1	7	10	1
CR Participant. Verification. (CW task5)	1	3	8	9	1
Review (No of Participants)	N/A	6	16	12	N/A
Approve (Engineer)	1	4	6	9	1
Approve (Approver)	1	2	3	2	1
Approve (Manager Level 1)	1	N/A	2	1	N/A
Approve (Manager Level 2)	1	N/A	1	N/A	N/A
Approve (Manager Level 3)	N/A	N/A	N/A	N/A	N/A
Approved Close out	1	1	3	2	2
Rejected Close out	1	1	3	2	1

4.4.3 Project Team Member's (Resource) Availability Percentage

It is important to know how much time a project team member has spent in the change request workflow tasks related to evaluating the CRs. This contributes to the resource availability percentage that needs to be considered for each resource defined in the simulation model. In Simul8™, when a resource is assigned to a work centre, its 'availability percent' is, by default, set to 100% which means the resource is fully available in that particular work centre to work on an entity upon its arrival. Considering this, a queue never builds up before that work centre unless the arriving entity finds both the work centre and the resource assigned to it busy. But this was not the case happening in the change request workflow. In the database analysis, based on each CR's (workflow instance's) time stamps and the project team members who had worked on the CR in each workflow task, the following formula was considered to calculate the resource availability for each resource (project team member):

$$Resource\ \text{“}A\text{”}\ Availability\ Percent = \frac{Nominal\ Working\ Time\ (N_t)}{Waiting\ Time\ (W_t) + Nominal\ Working\ Time} \times 100$$

The formula and the explanation of the nominal working time and the waiting time are covered in Section 4.2. Table 4-7 demonstrates the availability percent for each resource considered for the simulation model. For some resources this percent of availability is around 81%, and for some it is 0.32%. For instance, according to the database analysis, for the resource (project team member) who has been involved in "review engineer", "change request participant verification", and "approve engineer" and has received 7 CRs in total, this 81% resource availability means that the resource has had 81 and 19 hours as nominal working time and waiting time respectively. By the same token, the resource (project team member) with 0.32% availability, as the database analysis indicates, has been busy in the workflow for 0.32 hours to evaluate 19 CRs in "Review Participants".

Table 4-7: Resource availability Percentage calculation (OGP2)

Resources (Project Team members)*	Nominal Working Time (N_t)	Wait Time (W_t)	Resource Availability %age $(\frac{Nt}{Nt+Wt} \times 100)$	Modified Resource Availability
A	176.40	52.22	81.43%	**60%**
B	109.48	95.43	53.43%	53.43%
C	206.02	501.02	29.14%	29.14%
D	68.74	242.01	22.12%	22.12%
E	15.20	788.39	1.89%	**10%**
F	8.04	144.92	5.25%	**10%**
G	574.29	1236.99	31.29%	31.29%
H	0.24	23.22	1.04%	**10%**
I	501.50	800.67	38.51%	38.51%
J	180.84	727.74	19.90%	19.90%
K	0.61	207.97	0.29%	**10%**
L	10.69	0.74	93.51%	**60%**
M	123.78	328.80	27.35%	27.35%
N	0.45	139.29	0.32%	**10%**
O	5.90	1157.92	0.51%	**10%**
P	121.51	433.44	21.90%	21.90%
Q	31.73	1243.70	2.49%	**10%**
R	0.50	2.50	16.68%	16.68%
S	2801.90	1460.17	65.74%	**60%**
T	9.72	1061.40	0.91%	**10%**
U	1.06	399.67	0.27%	**10%**
V	19.95	109.28	15.44%	15.44%
W	3.22	16.31	16.49%	16.49%
X	3.50	181.81	1.89%	**10%**
Y	649.17	742.87	46.63%	46.63%
Z	204.31	1402.37	12.81%	12.81%
AA	4.87	3.38	59.01%	59.01%
AB	0.04	14.43	0.25%	**10%**
*: Due to confidentiality the names of the project team members are replaced with alphabets				

A key point in here is how reliable this percentage of availability can be. This leads to the topic of the *capturibility of the workflow's behavior*. In other words, what sort of the workflow's time-based behavior can be captured and what sort cannot? This is one of the challenges in the development of the change request workflow simulation model that will be discussed in the next Section.

4.4.4 Capturability of the Workflow Behavior

In the process of change request evaluation, from inception to completion, there exist two types of times; *capturable times* and *uncapturable times*. The capturable times are:

- Created Date Time
- Ownership Date Time
- Completion Date Time

The explanation of these times is covered in the Section 4.1.3 of this Chapter. Uncapturable times, on the other hand, are concerned with the tasks that, although time dependent, happen outside of the process of change request. Some of these uncapturable times are:

- Time spent for meetings, thinking, negotiations, and phone calls relevant to the evaluation of the CR(s)
- Time spent out of the change request workflow system to evaluate a change request (e.g.: calculation of the cost impact, studying other relevant documents), and
- "Sitting" on a document.

In most of the CRs, those stakeholders who are involved in the process of the change request evaluation must hold meetings and negotiations in order to clarify any confusion about cost or schedule impact of the CR request on the project and to avoid any potential litigation due to the ambiguity about the document. Even during the process of CR evaluation, a project team member may open the CR document in the automated change request workflow and notice that more clarification on the CR is required. Therefore, he or she may make a phone call to a colleague and spend one or two hours on the phone about the CR document. In any of these cases, the time, although spent for the evaluation of the CR document, is not recorded in the database of the automated process.

It can be argued that these meetings or phone call times are in parallel with the waiting time of the CR in any tasks of the workflow. That is, the waiting time of the CR should be to some extent considered as the working time for that CR. Although this argument is correct, the author of this thesis argues that the percent of the waiting time that must be considered as the working time and added to the availability of the resource in the workflow still remains unclear.

As the analysis of the database showed, even when a CR had been open for the long period of time in the workflow, (e.g.: 14:00:00 hours or more), it did not necessarily mean that the project team member had been working on the CR. It is likely that the project team member may have been distracted by some work which was not concerned with the evaluation of the CR while the CR had been left open in the workflow. Or, the project team member may have left the workflow open late in the evening, for instance around 6:00 p.m. and may have come back to it in the morning around 8:00 a.m., and that's why the database shows 14:00:00 hours as the nominal working time. The timelines in Figure 4-2 graphically illustrates these hypothetical scenarios.

The uncapturability of the workflow behavior has direct impact on the percent availability of the resources used in the simulation model of the change request workflow. In the resources availability percentage calculation, shown in Table 4-7, only the capturable times in the workflow were considered. This gave inaccurate results when implemented as the input data in the simulation workflow. Therefore, the simulation outputs could not be validated with the actual results of resources' (project team members) of the workflow. To overcome this problem, some informed estimation for the resources' percent availabilities was contemplated. During a phone interview, the business analyst of the project mentioned that the percent availability of the project team members (resources) should be assumed between 10% and 60%. Therefore, the confidence limit of 10% and 60% were assumed for those resources whose availability was either below 10% or over 60%. This modification is reflected in the last column of Table 4-7, “modified resource availability”. The validation of the simulation model of the change request workflow based on this estimation is shown in the data analysis, Section 4.6 and Chapter five.

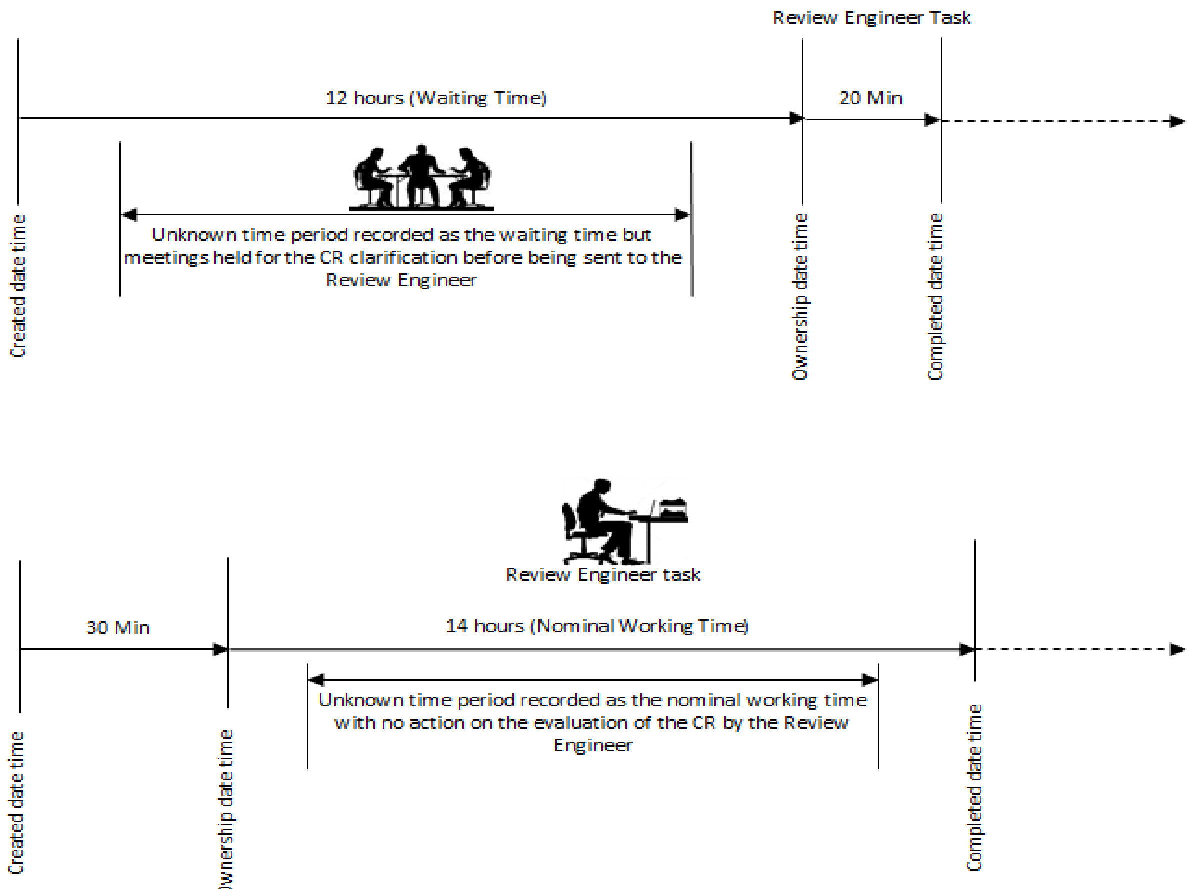


Figure 4-2: Examples of unknown time periods as the uncaptured behavior of the workflow

4.4.5 Discrepancy between the Simulation Model of a Change Request Workflow and That of a Factory Floor

In order to better understand the above challenges in characterizing time allocation of professionals, a comparison between the simulation model of the change request workflow and that of a factory floor is useful.

Let us consider the scenario of a quality control task in the production line of a factory floor where the products arrive every two minutes exponentially distributed to the Quality Control (QC) work centre. The quality controller, assigned as a full time job, takes three minutes on average normally distributed to check the product and then send it off for loading (Figure 4-3)

Figure 4-3: Simulation of Quality Control task in a factory floor

Figure 4-3 clearly illustrates the queue built up in the production line. To minimize or eliminate the queue, production managers, as one strategy, can increase the number of Quality Controllers. The contributing factors to realistically simulate this production line are:

- The type of materials (entity) under the quality control task is homogenous.
- The quality controller is fully available for the task given (The relief is available in case of laborer's absence). Hence the time spent on each item in the process is capturable.

Unlike the aforesaid factors, the types of change requests in the change request workflow are heterogonous (different) in the sense that some require more time in the form of meetings and negotiations (especially if the dollar amount is considerable). This time period, although spent for that particular change request, is not captured. The resource availability percentage is another issue when it comes to simulating the change request workflow. This issue is explained in 4.4.3. According to the discrepancy explained above, some simplifying assumptions must be made in order to effectively simulate CR process workflows for subsequent analysis.

4.5 Simplification of the Change Request Workflow in the Simulation Model

In this Section, a simplified form of the simulation model without compromising the validity of the model is suggested. It forms the basis for the working simulation model used later. The first subsection covers the number of workflow instances used to develop the simulation model of the change request workflow. The second subsection focuses on the number of project team members defined as the resource pool for the simulation model.

4.5.1 The Number of Workflow Instances and Workflow Implementation

Due to the complexity of the data and traceability of a document in each task of the workflow, the 72 change requests in OGP2 was examined first, since these documents were found more traceable. As stated before, in both OGP1 and OGP2 the same workflow template and the same workflow implementations were used. In OGP2 data analysis, 8 out of 72 change requests were incomplete workflow instances. That is, they were initiated but never reached to either the approved or the rejected close out task. These 8 incomplete change requests, defined as outliers, were taken out, and only 64 complete instances were considered for analysis and input data for the simulation. As shown in Table 4-6, for OGP2 the number of instances in each implementation of the workflow was not sufficient enough to simulate each workflow implementation respectively. Therefore, all workflow implementations of OGP2 were considered as one unique implementation in which 64 instances existed.

4.5.2 The Number of Resources Assigned to a Workflow Work Centre

As shown in Figure 4-1 and also stated before in section 4.3.3 of this Chapter, the project team members in the same color-coded tasks were presumed to be the same person. However, the data analysis showed differences in some cases. For instance, if the project team member 'A', who had sent a change request (CR) from "Review Engineer" task to "Review Participants" task, was not available to receive the reviewed CR in the "Approve Engineer" task, the project team member 'B' was reassigned to receive the CR. The analysis of the database showed that this "reassignment" happened in the tasks with "time-out warning". "Time-out warning" occurs when a project team member in a particular task misses the due date (the date given in 'Response By' column in the database table, see Table 4-1) by when a CR should have been responded to. Then the sender may resend the CR to the same task but assigned to a different project team member who is equally qualified to respond to the CR. Considering this, the data analysis indicated that there were a couple of project team members who were routinely assigned to one or a couple of tasks whereas some project team members were occasionally seen in only one task. Without compromising the simulation results, the resource pool of the change request workflow simulation model was developed based on those project team members who were most frequently active in their assigned tasks.

4.6 Input Data Analysis

The discrete-event simulation (DES) model of the workflow included two main types of input data; *inter-arrival times* of the change requests and the *service time* of the work centres (tasks) of the workflow. The former is covered in subsection 4.6.1 and the latter in subsection 4.6.2.

4.6.1 Inter-Arrival Times (IATs) of the Change Requests

Since the inter-arrival time represents the times between the arrivals from a large calling population (See Section 3.6.1) acting independently of one another, the inter-arrival time can be hypothesized to be ‘exponential’ and the arrival process to be Poisson (Roess, 2004; Banks et al, 2009) To such hypotheses, Simul8^{TM} has the feature named “Stat::fit” through which this distribution was calculated. Although the exponential distribution is not the top distribution in the Stat::Fit graphs, it is “not rejected” and is close to the top distribution which is gamma. It should be noted that, “*exponential distribution is a classic distribution used for arrival times of anything where one arrival is independent of the next… examples are customers arriving at a store or patients arriving at a hospital”* [Simul8.com last accessed 16/03/2014]. This description, thus, clearly justifies that the use of exponential distribution is an acceptable choice for the arrivals of the change request documents to the system, because they are not only independent from each other but also, as the data analysis showed, several documents, either one by one or as a batch, are sent with time gaps between them.

There are 4 types of change requests (CRs) arriving in different times and dates in all 8 workflows implementations. As the first trial to calculate the inter-arrival time (IAT), the arrival times of each type of CR in each workflow implementation were used. This approach led to inaccurate inter-arrival times to select the proper distribution especially in some workflow implementations with few workflow instances (see the number of workflow instances in the implementations 3, 4, 5, and 8 of OGP2 in Table 4-3). In an alternative approach, in order to generate a larger calling population of CRs leading to more accurate inter-arrival times, all workflow implementations were assumed as one integrated workflow implementation, then the inter-arrival times were calculated for each type of CRs respectively. This assumption cannot be wrong since shifting from one workflow implementation to another was continuous with overlap time between them.

Table 4-8 includes the inter-arrival times for each of the Engineering, Vender, Field, and Contract type of change requests for both OGP1 and OGP2. Since the distribution is exponential for all types of CRs’ inter-arrival times, the rate parameter or Lambda (λ) is calculated as follows:

$$E(X) = \frac{1}{\lambda} \; or \; \lambda = \frac{1}{E(X)}$$

In the above equation, E(X) is defined as the mean or expected value of change request arrival times.

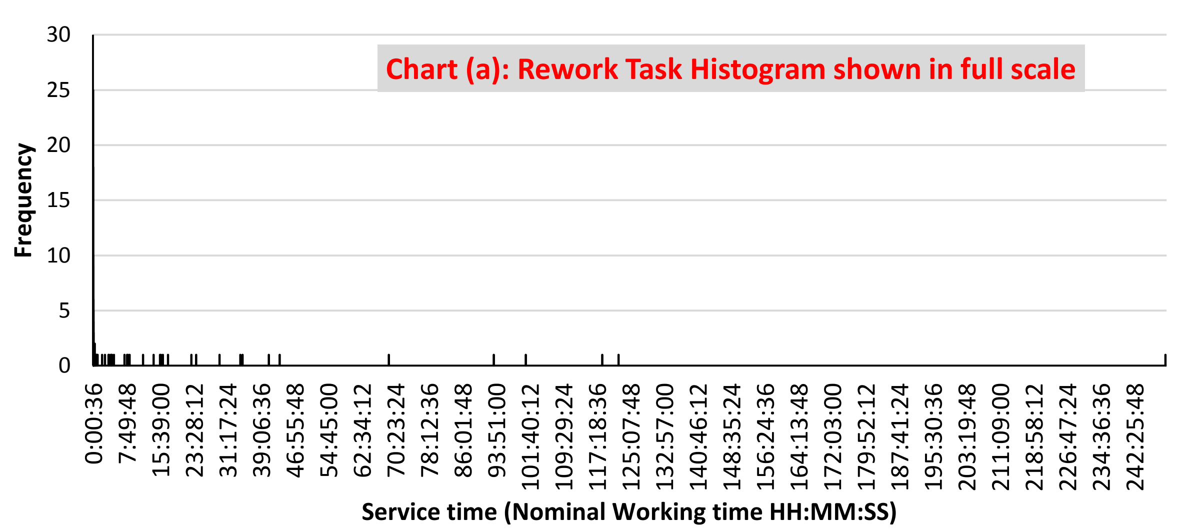
Table 4-8: Inter-arrival rate of change requests in OGP1 and OGP2

Change Request (CR) Type	Distribution	Inter-arrival rate of change requests (12 Working Hours/Day)	
		OGP1	OGP2
Contract	Exponential	Lambda = 0.06	Lambda = 0.026
Engineering		Lambda = 0.033	Lambda = 0.039
Field		Lambda = 0.015	Lambda = 0.014
Vendor		Lambda = 0.073	Lambda = 0.018

4.6.2 Service Times in Activity Centres or Tasks in the Change Request Workflow

In the simulation model of the change request workflow, a work centre (also called activity centre) represents a predefined task that a resource (project team member), who is assigned to that work centre, does on a change request upon its arrival. Like the simulation model's entry point (Entry or Start Point is explained in 4.7 and Section 5.1.1 of Chapter five) where, based on a certain distribution (exponential), the arrival rate of the change request documents are simulated, the working behavior of a work centre in the workflow is the function of a distribution defined as per the nominal working hours of resource(s) assigned to that work centre.

In addition to "Stat::Fit" which is a tool in Simul8™ to fit a distribution to the data given, there exist different types of predefined distributions in Simul8™. As the first approach, the service time (nominal working hours) for each task was calculated (see Figures Figure 4-4, Figure 4-5, Figure 4-6, and Figure 4-7) given to "Stat::Fit" to fit the proper distribution for the task. For most tasks, all distributions offered by "Stat::Fit" got *rejected*. For instance, Figure 4-8 depicts all distributions rejected for the "Approved Close Out" task.



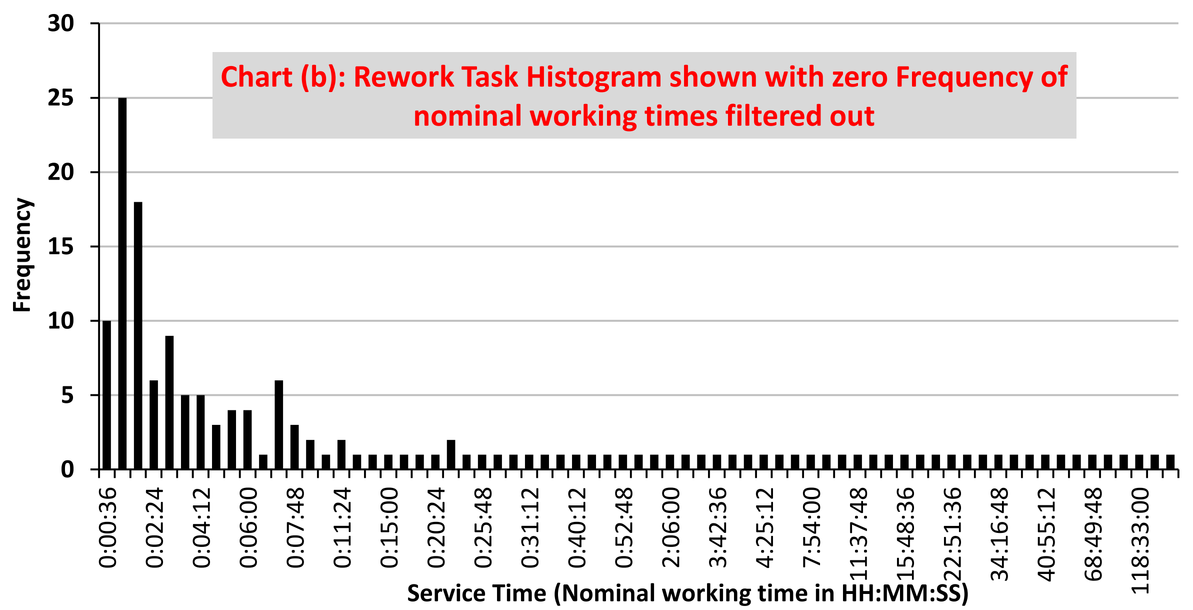
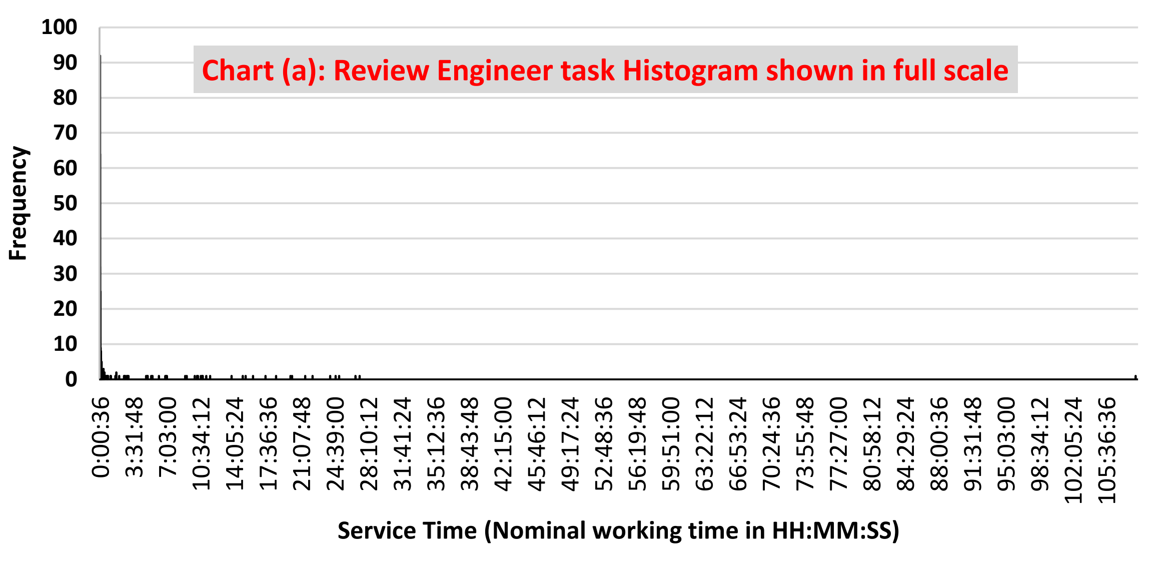


Figure 4-4: Histogram of service time of Rework task

Chart (a) of Figure 4-4 illustrates the rework task histogram in full scale. The horizontal axis starts from 00:00:00 to 250:00:00 with 00:00:36 increments. While the majority of the CRs' nominal working time is less than a couple of minutes, occasionally a CR's nominal working time has taken hours. This is better shown in Chart (b) where the nominal working times with zero frequency are filtered out.



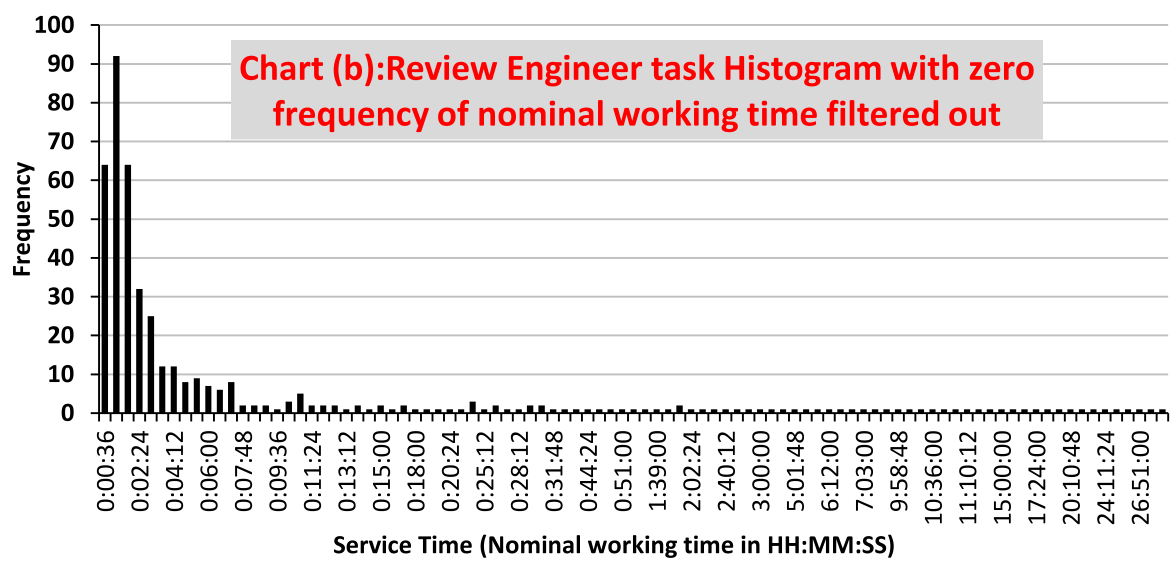
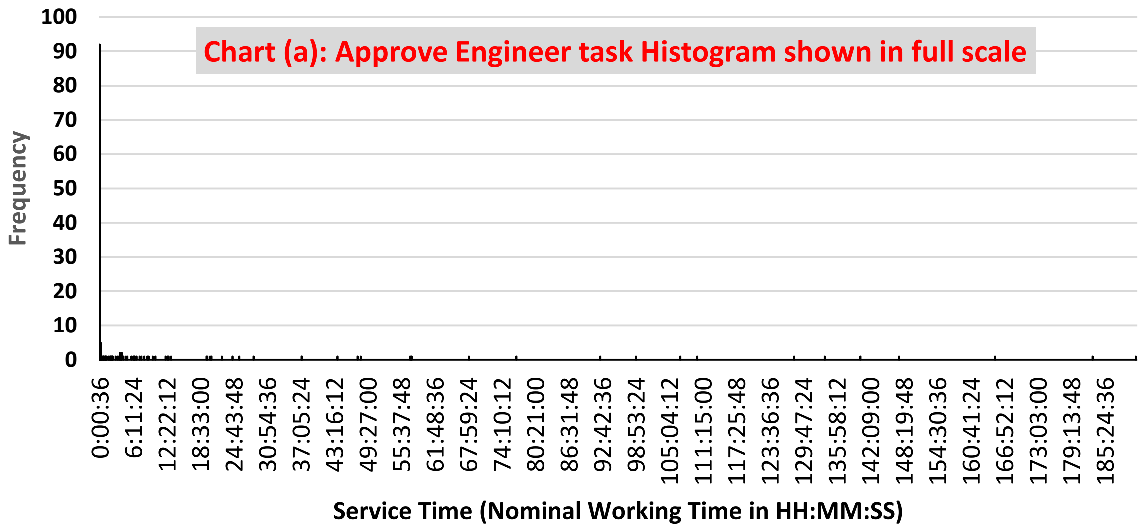


Figure 4-5: Histogram of service time of Review Engineer task

Chart (a) of Figure 4-5 illustrates the Review Engineering task histogram in full scale. The horizontal axis starts from 00:00:00 to 250:00:00 with 00:00:36 increments. While the majority of the CRs' nominal working time is less than a couple of minutes, occasionally a CR's nominal working time has taken hours. This is better shown in Chart (b) where the nominal working times with zero frequency are filtered out.



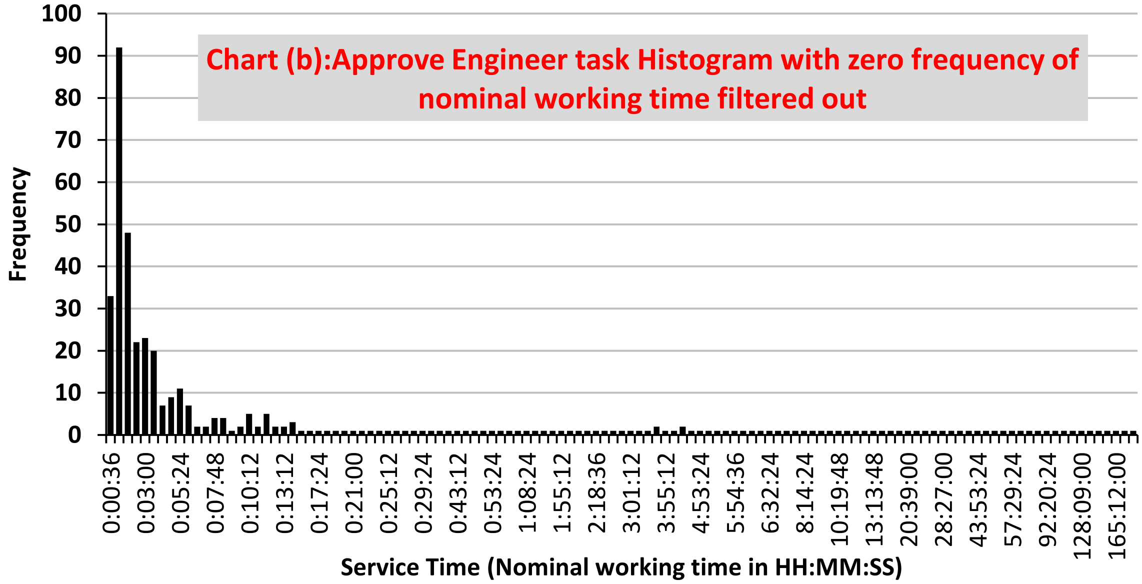


Figure 4-6: Histogram of service time of Approve Engineer task

Chart (a) of Figure 4-6 illustrates the Approve Engineering task histogram in full scale. The horizontal axis starts from 00:00:00 to 191:30:00 with 00:00:36 increments. While the majority of the CRs' nominal working time is less than a couple of minutes, occasionally a CR's nominal working time has taken hours. This is better shown in Chart (b) where the nominal working times with zero frequency are filtered out.

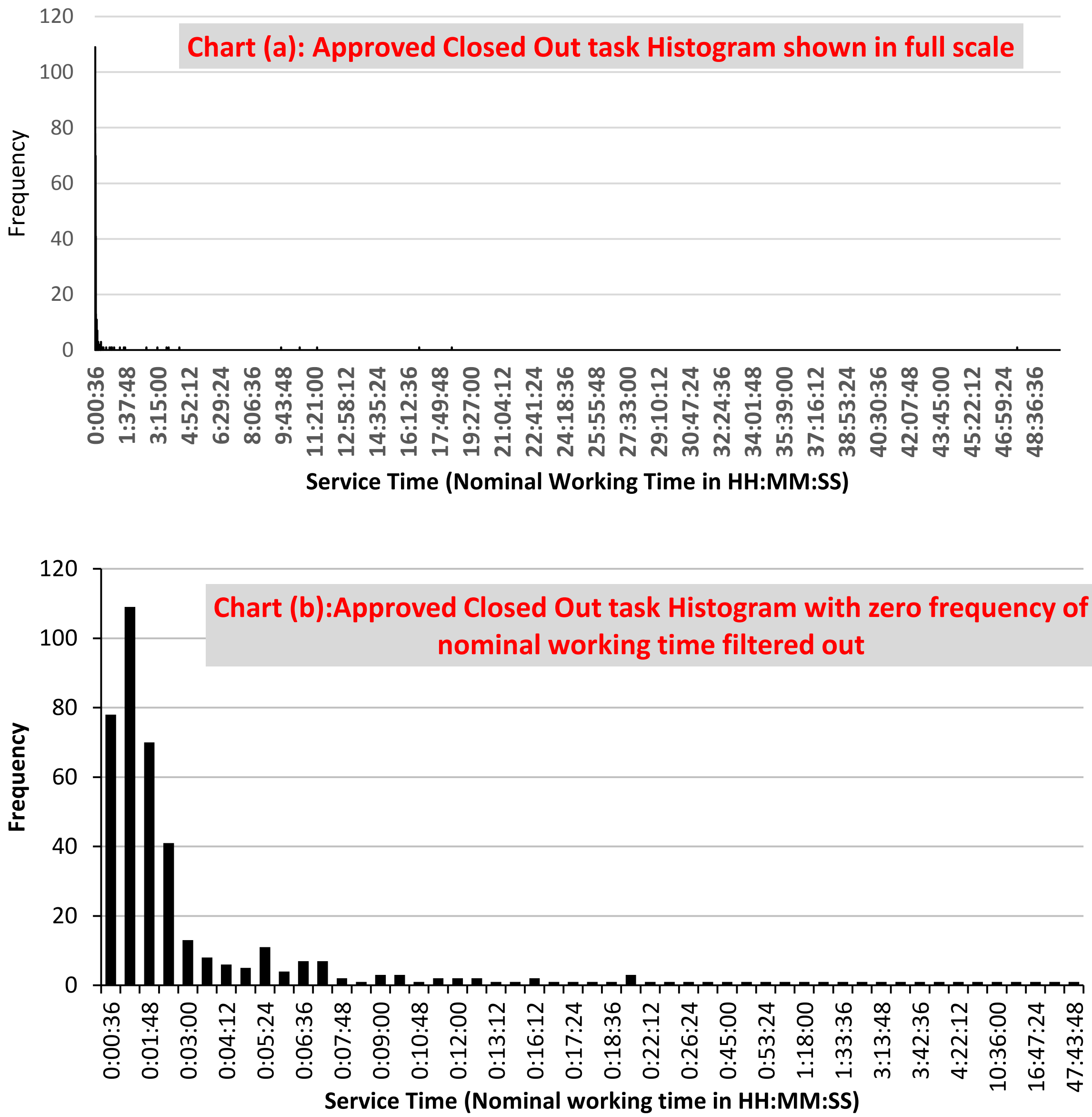


Figure 4-7: Histogram of service time of Approved Closed Out task

Chart (a) of Figure 4-7 illustrates the Approved Closed Out task histogram in full scale. The horizontal axis starts from 00:00:00 to 50:00:00 with 00:00:36 increments. While the majority of the CRs' nominal working time is less than a couple of minutes, occasionally a CR's nominal working time has taken hours. This is better shown in Chart (b) where the nominal working times with zero frequency are filtered out.

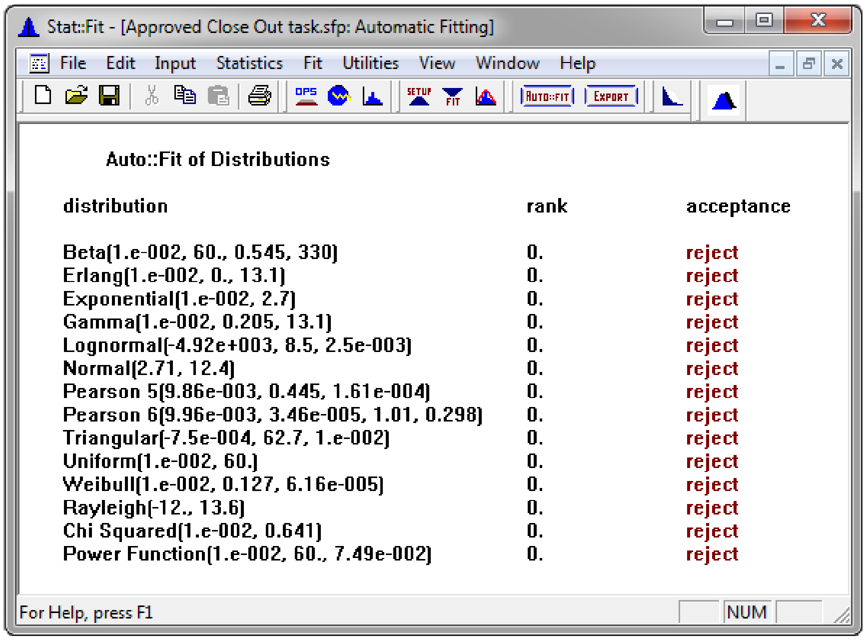


Figure 4-8: “Rejected” distributions for “Approved Close Out” task in “Stat::Fit”

In Simul8™, the data source of the “External distribution” can be Excel or Visual Basic (see Figure 4-9c). The Excel External distribution, selected for the workflow tasks, works when a new distribution is defined in Simul8™ and the empirical data is defined in a column (or row) of an excel sheet (Figure 4-9). During the running time of the simulation model of the change request workflow, when a change request document arrives at a task or work (activity) centre, the variable in the first cell of the column of that excel sheet is selected as the service time for that task or more accurately as the nominal working time for the resource assigned to the task. When the second change request document arrives, the variable in the second cell of the column is selected as the new service time for the task. This sequence goes on to the last cell of the column after which there is no data stored. Should there be another change request document arriving at the task, the variable of the first cell is *re*selected for the task. This type of variables selection was static and always led to the same result after each simulation run. To overcome this issue, Monte Carlo simulation technique and some appropriate Excel formulas were used in the data column to *randomly* replace the variables in the cells. So, when a change request document arrived to a task, a randomized variable from the corresponding cell was selected. Based on this approach, the task (work centre) in the simulation model of the change request workflow behaves just like that in the actual change request workflow. The details of creating the External distribution are projected in the following paragraph and in Figure 4-9.

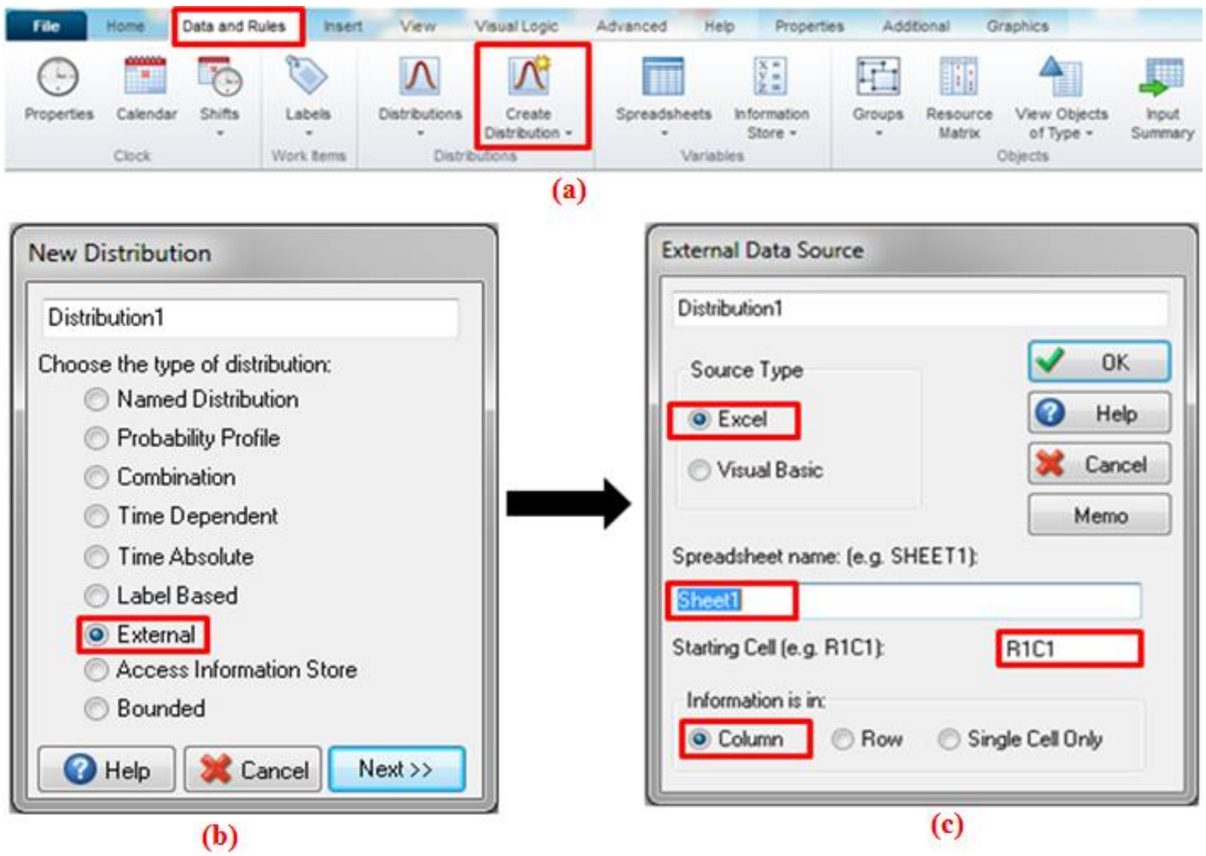


Figure 4-9: Creating an External distribution with empirical data for workflow tasks

Considering Simul8^{TM} is open, select the “Create Distribution” from the “Data and Rules” tab (Figure 4-9a). From the “New Distribution” dialog box name the distribution, select the “External” radio button, and click “Next” (Figure 4-9b). In the “External Data Source”, select radio button “Excel” as one of the two ways the External distribution’s source type can be defined. If required, in “Spreadsheet name” name the spreadsheet from which the stored data is to be extracted. In the

"Starting Cell", enter the address of the first cell of a column or row in which the data stored. By default, the "Starting Cell" is set on R1C1 which represents A1 cell in a spreadsheet. Simul8™, while running, considers that cell as the starting cell and goes down through the column of data, if "Column" radio button is selected in the "Information is in:" Section (Figure 4-9c).

4.7 The Change Request Workflow Simulation Model and Its Components in Simul8™

Simul8™ provides an environment in which the simulation model of the change request workflow based on its conceptual model (Figure 4-1), inter-arrival rates of the change requests, service times of tasks, and the number of resources assigned to each task can be developed. Table 4-9 contains the components used in the simulation model of the workflow designed in Simul8™ (Figure 4-10).

Considering the iconography and the descriptions of the components, the following points are also worth mentioning:

- Since there are four different types of change requests; Engineering, Vendor, Field, and Contract Change Requests, it seemed more logical to define four distinct Start Points each of which exclusively generate one type of change request. This approach, when implemented resulted in inaccurate verification of the inter-arrival times of change requests (see Section 5.1). Therefore, *one* Start Point was considered to generate the arrival of each change request respectively. This alternative approach, as explained in Section 5.1, led to the reliable verification of the inter-arrival times.

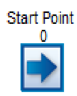
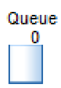
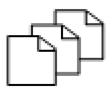
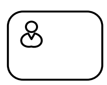
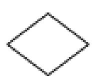
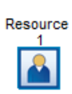
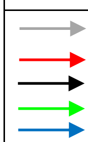
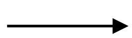
- The implementation of the workflow tasks fell into two main categories; the first category included the *Activity (work) Centres* representing human-based tasks such as "Verify Details" or "Review Engineer" and the second was *"Dummy Distributors"* representing machine-based gateways on the actual change request workflow. These Dummy Distributers were used just to direct the change request documents to the predefined routes in *zero time*. The zero time means that the Dummy Distributor spends no time to send the change request to the predefined routes. To do this, the distribution of the Dummy Distributors was considered as “fixed” type with the “fixed value” equal to zero.

- Since at the end of the workflow, a change request document ended up being either rejected or approved, two “End Points” were defined; one for “Approved Closed Out” change request documents and the other for “Rejected Close Out” change request documents. This provided a better control over the data analysis of the simulation results in the workflow simulation model and its validation/verification.

Figure 4-10 illustrates the change request workflow simulation model. This simulation model is constructed based on all human-based tasks of workflow implementations 1 to 8 (see appendices G1 to G8) and the conceptualized model of these implementations shown in Figure 4-1. In order to demonstrate its details, this simulation model is broken down to distinct segments. Each segment, as shown in Figure 4-10, is enclosed in a black broken-line box. Figure 4-11, Figure 4-12, and Figure 4-13 illustrate these segments respectively.

Graphically speaking, the simulation model (Figure 4-10) seems more complex than the conceptual model (Figure 4-1) of change request workflow. Since there were four types of change requests, four distinct paths and four distinct activity centres were required in most parts of the simulation model. For instance, as shown in Figure 4-11 and also Figure 4- “Verify Details” task includes “Verify Details ECR (Engineering)”, “Verify Details VCR (Vendor)”, “Verify Details FCR (Field)”, and “Verify Details CCR (Contract)”. Above these, the “Dummy Verify Details Distributer” identifies the type of the change request and then sends it to its predefined exclusive path. This approach resulted in better validation of the simulation model, since it led to better visual traceability of each type of change request in the simulation model while it was running in addition to segregated results for both end points (Approved/Rejected Close Out) and activity centres based on each type of change request. In Chapter five, Section 5.2.4 explains these points in more detail and Figure 5-7 in Chapter 5 demonstrates the segregated results for the two end points.

Table 4-9: Iconography and description of the simulation components

Icon	Definition	Icon in Conceptual Model (Figure 4-1)	Description
	Start Point		Start Point generates the change request documents into the simulation model, based on Change requests' inter-arrival times and the distribution defined.
	Queue		Defined before the Activity Centres, queues store the arriving change requests when the Activity Centre is occupied with a change request.
	Activity (Human-based task)		Work (Activity) Centres represent human-based tasks. Their service time, when a CR arrives, depends on the distribution defined and the availability of the resource(s) assigned to it.
	Dummy (Machine-based task)		Dummy Distributers represent machine-based tasks. With no resource assigned, They only route out the change requests in zero service time.
	End Point		End Point represents the point where the simulation model collects the rejected or approved change requests respectively.
	Resources		Representing the users in the change request workflow, resources are assigned to the Activity Centres to evaluate the arriving change requests.
	Paths		Paths represent the sequence of tasks; The red represents the *exclusive* path for Engineering, the black for Vendor, the green for Field, and the blue for Contract CRs. The gray represents the *general* paths for all four types of CRs.

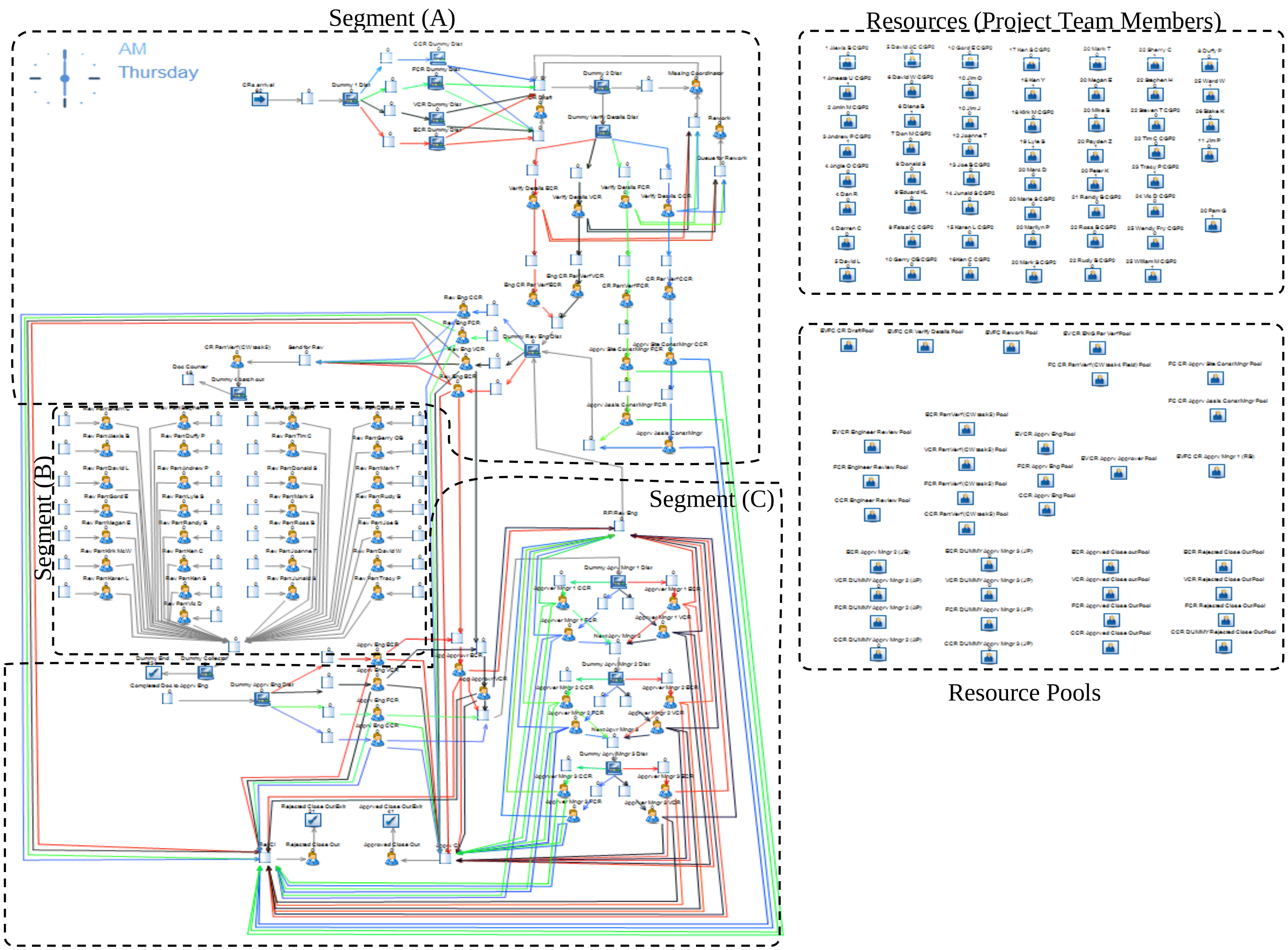


Figure 4-10: Simulation Model of the Change Request Workflow

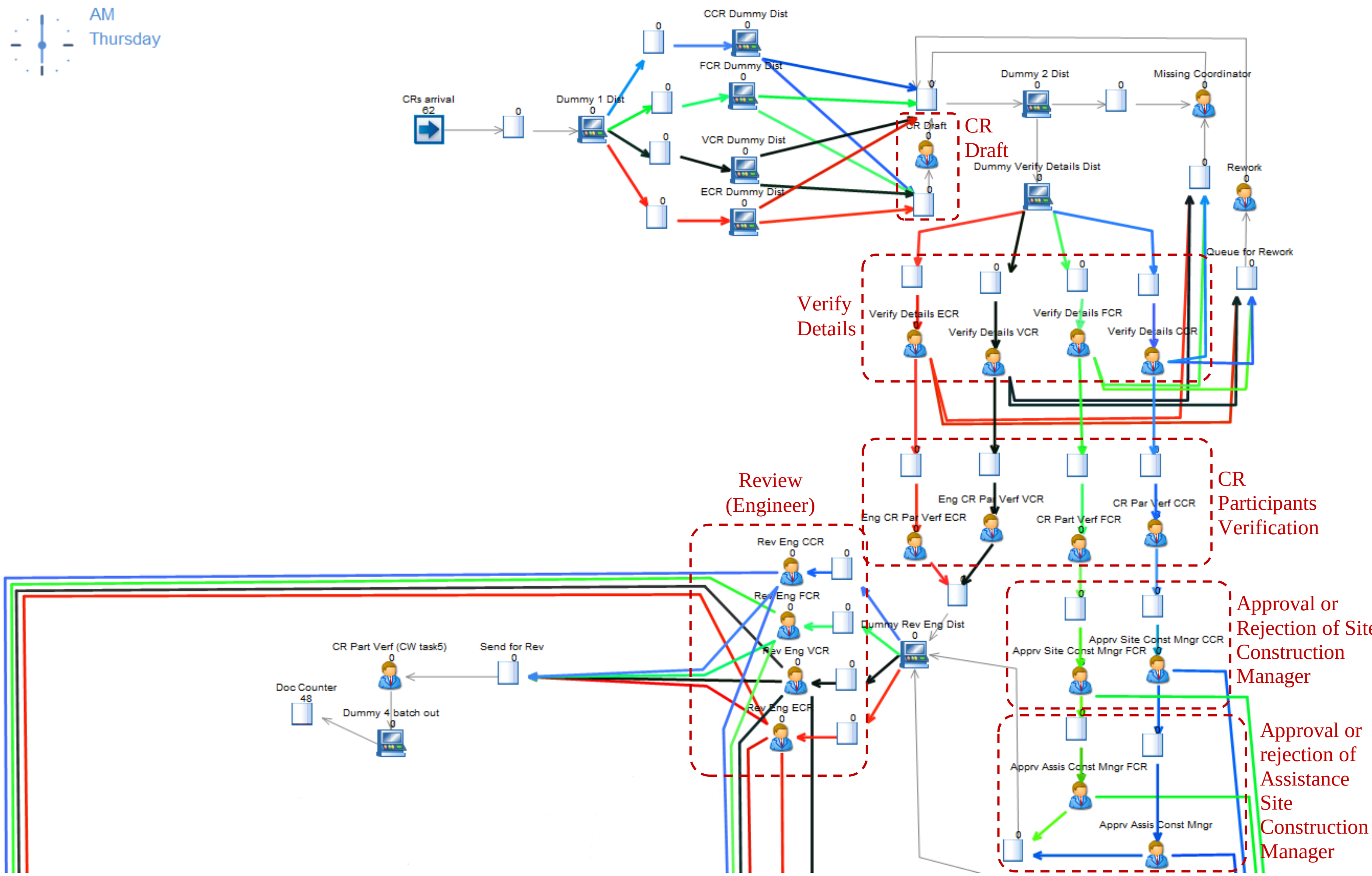


Figure 4-11: Segment (A) of the Simulation Model of the Change Request Workflow in Figure 4-10

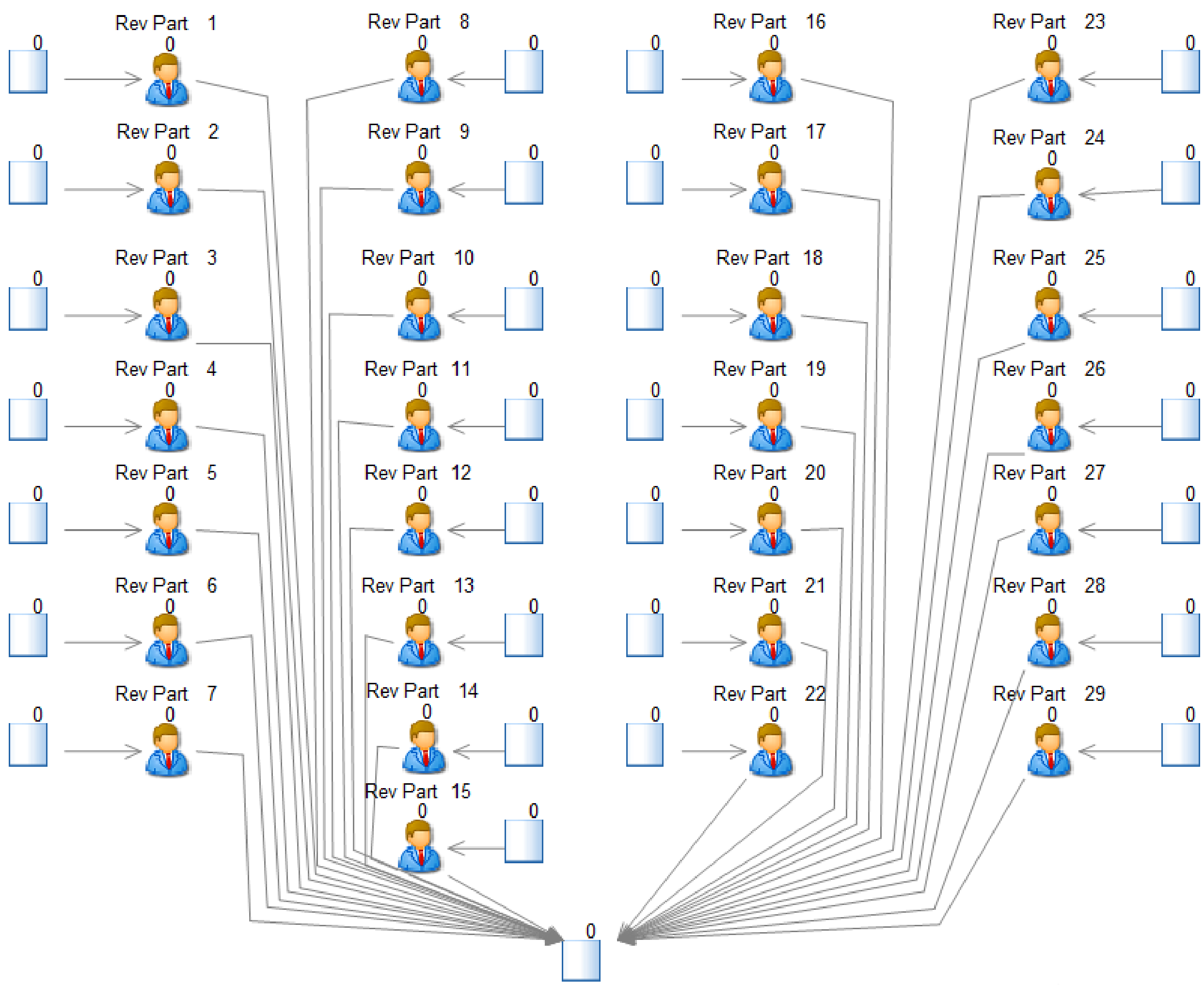


Figure 4-12: Segment (B) of the Simulation Model of the Change Request Workflow in Figure 4-10

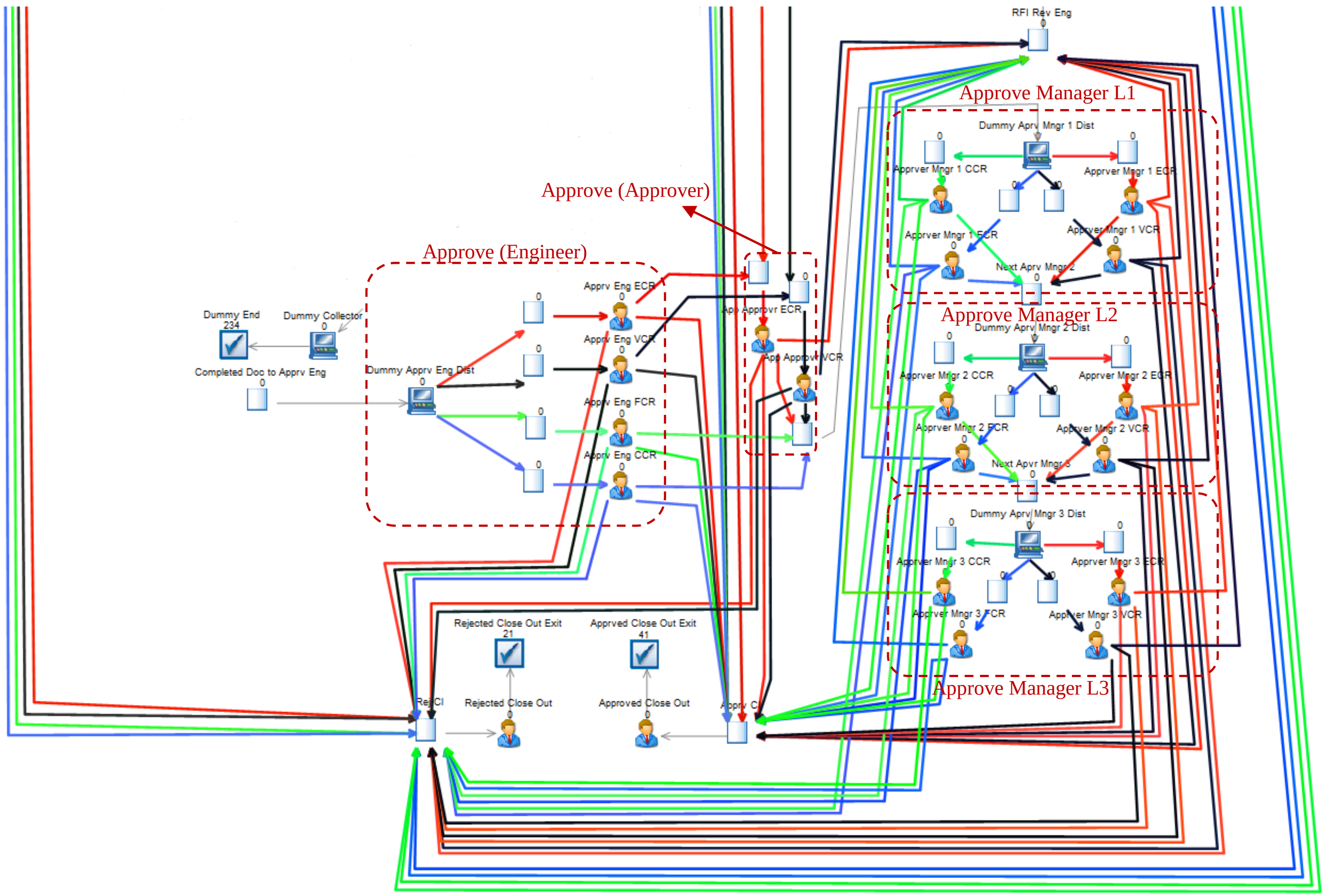


Figure 4-13: Segment (C) of the Simulation Model of the Change Request Workflow in Figure 4-10

In addition to segments (A), (B), and (C) of the simulation model each of which are magnified and shown in detail in Figure 4-11, Figure 4-12, and Figure 4-13 respectively, Figure 4-10 contains "Resources (Project Team Members)" and "Resource Pools" both of which are magnified in Figure 4-14. The former represents each Project Team Member individual who has been active in OGP2 change request workflow. According to database analysis, any of these individuals who were involved in "Review Participants" task, were *directly* assigned to their correspondent "Review Participant" activity centres shown as segment (B) in the simulation model (Figure 4-12). The latter represent a resource pool that includes more than one project team member. Through a resource pool, a resource (a project team member) was *indirectly* assigned to an activity centre. For instance, according to database analysis, resources (A), (B), and (M) were involved in "Verify Details" task. Therefore, a resource pool, named "EVFC CR Verify Details Pool" (Engineering, Vendor, Field, Contract Change request Verify Details Pool) in which the aforementioned resources were included, was defined. Then, this resource pool was assigned to all four "Verify Details" activity centres in the simulation model. While simulation model's running, the "Verify Details" activity centre, when receiving a change request, pulled a resource from the "EVFC CR Verify Details Pool" to work on the change request.

The simulation model showed inaccurate results when "resource pools" were not used, as the first approach. Therefore, the resource pools, as an alternative approach, were defined to overcome this challenge.

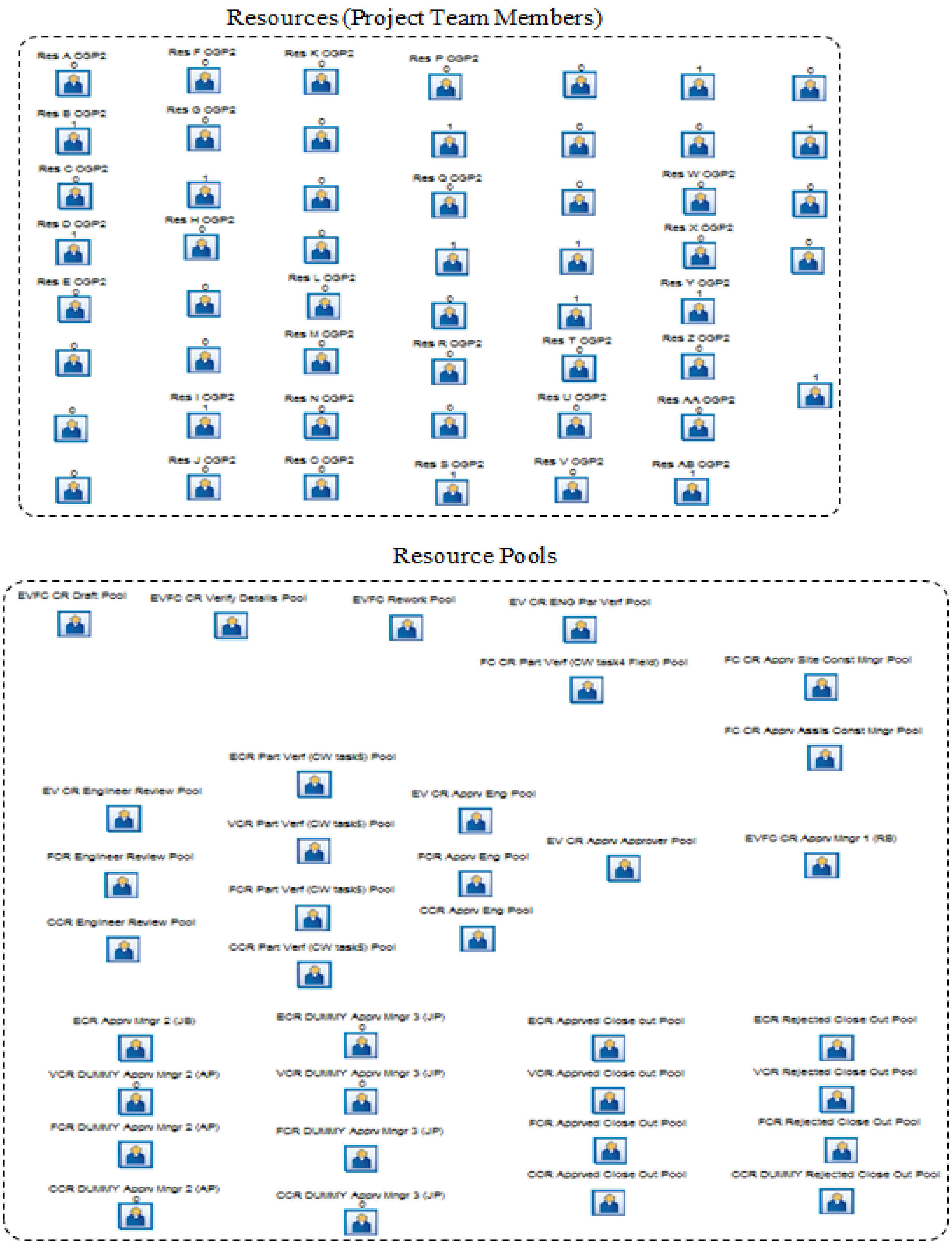


Figure 4-14: Resources (Project Team Members) and Resource Pools

4.8 Simul8™'s Commands

In order to get the model to simulate as the real workflow effectively, some Simul8's commands were implemented in the simulation model. These commands are described in the following Sections.

4.8.1 Work (Activity) Centre Replicate

The data analysis indicated that the number of project team members varied in different tasks of the change request workflow. For instance, in "verify details" there were 3 project team members assigned to this task. The analysis of the workflow showed that these three project team members worked in parallel on the change request documents sequentially arriving to this task. For example, the first change request document goes to person "A" (project team member) to verify the details, while the person "A" is busy the second document goes to the person "B" and while both person "A" and "B" are busy the third document goes to person "C". Obviously a queue builds up when a new CR document finds all "A", "B", and "C" busy. This logic existed in all workflow tasks where more than one project team member was assigned to that task. To implement this logic in the simulation model of the workflow, the Simul8™'s "replicate" command was used.

This command is accessible when the work centre is highlighted and the "Additional" tab is selected. Then the number of replicates can be entered into the "Replicate" slot (Figure 4-15).

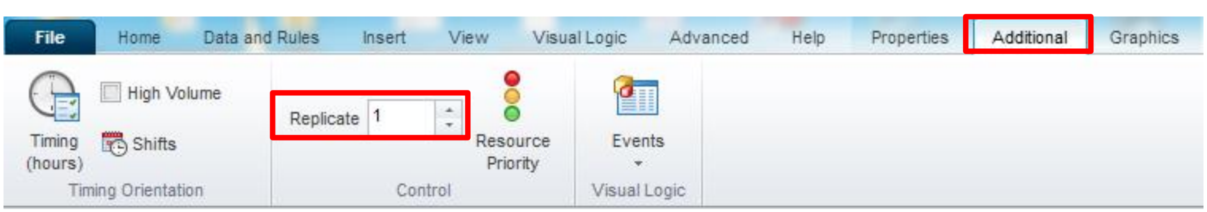


Figure 4-15: Number of replicates of a work centre

4.8.2 Clock Properties: Setting the Clock of the Simulation Model

Through this command the working hours and working days of the simulation (simulation's calendar) can be defined. The date and time stamps of the available data of OGP1 and OGP2 showed that the working hours were 12 hours per day on average and for 5 days a week from Monday to Friday. However, occasionally on weekends some change requests were evaluated. When contacted, the business analyst of the project also confirmed the 12 working hours per day starting at 6:00 AM as the start working time. Therefore, the simulation clock was set accordingly (Figure 4-16).

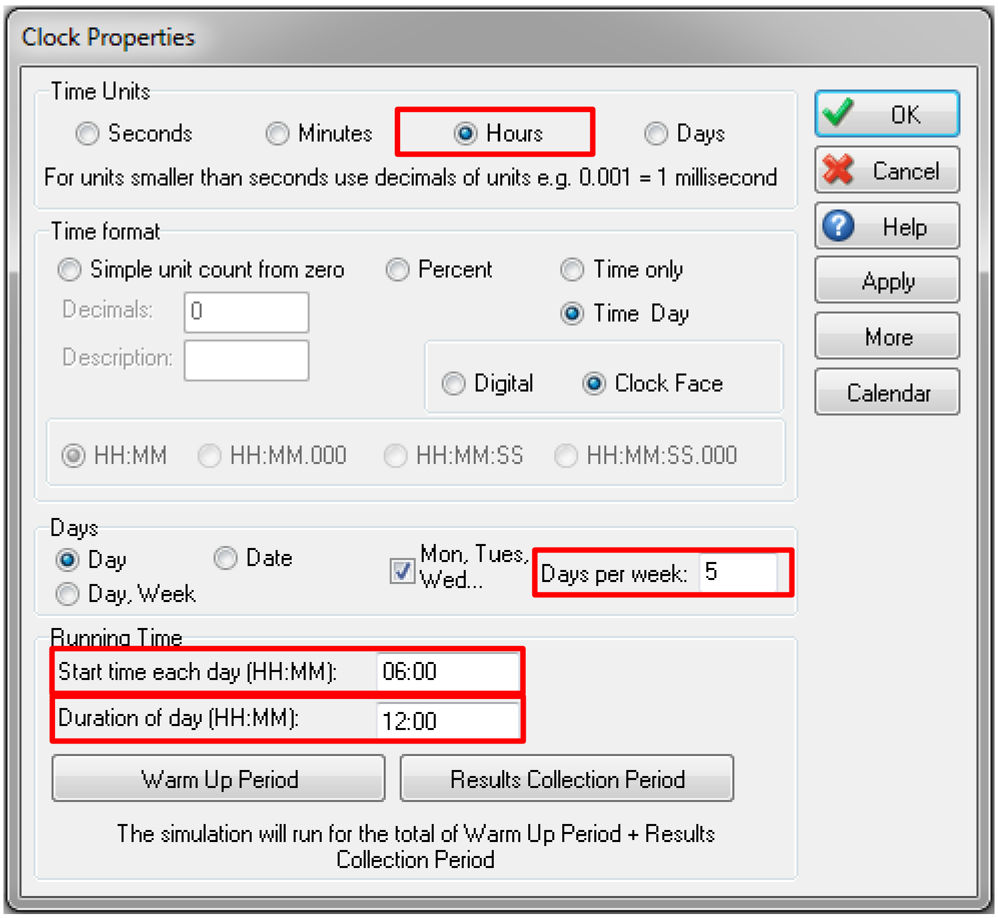


Figure 4-16: Setting the simulation clock

The working hours on the weekends were negligible when setting the simulation clock, since they took a small proportion of the whole working time the project team members had spent over the workflow in working days.

4.8.3 Visual Logic (Simul8^{TM}'s Coding Program Environment)

Visual Logic is a coding program used when the simulation model is to work in a way for which there exists no built-in feature or command. To accurately simulate the change request workflow, a couple of commands were programmed in Simul8^{TM} using Visual Logic. One of the most important commands was to establish the First in Random out (FIRO) behavior of the actual workflow in the simulation model especially in the "review participants" task. To implement this FIRO, visual logic coding for all four types of the change request document was used. Appendix (H) includes a sample of the coding lines used the implementation of FIRO for the ECRs.

4.8.4 Routing Out

"Routing Out" is a command that determines how the change requests in an activity centre are sent out to different directions. If the activity centre has more than one direction as the route out, it is required to calculate the percentage of the change requests routing out from an activity into the directions connected to that activity. To do this, the analysis of the OGP2 data was used, since as stated before, there were 64 complete change requests, the analysis of which was more feasible than OGP1 with 572 change requests.

The "Route Out" command for a selected activity centre is accessible through "routing out" in the "Properties" tab (See Figure 4-17 (a)). In the "Routing Out From:" dialog box, select "Percent" radio button and insert the percent of the highlighted direction (See Figure 4-17 (b)). Figure 4-17 shows the "Routing Out From" dialog box for the "Review Engineer" activity centre. In this Figure, for instance, 12.7% of the change requests in the "Review Engineer" activity centre was rejected and sent directly to the “Reject Close Out” activity centre (highlighted as “Rej Cl”). Likewise, all 64 change requests in OGP2 were tracked to find the precise percentage of change requests route out in each activity centre. For some activity centres the “route out” command was used with another command, named “Label” to accurately direct the each change request in accordance with their type (Vendor, Engineering, Field, Contracts) from one activity centre to another. “Label” is explained as the next command.

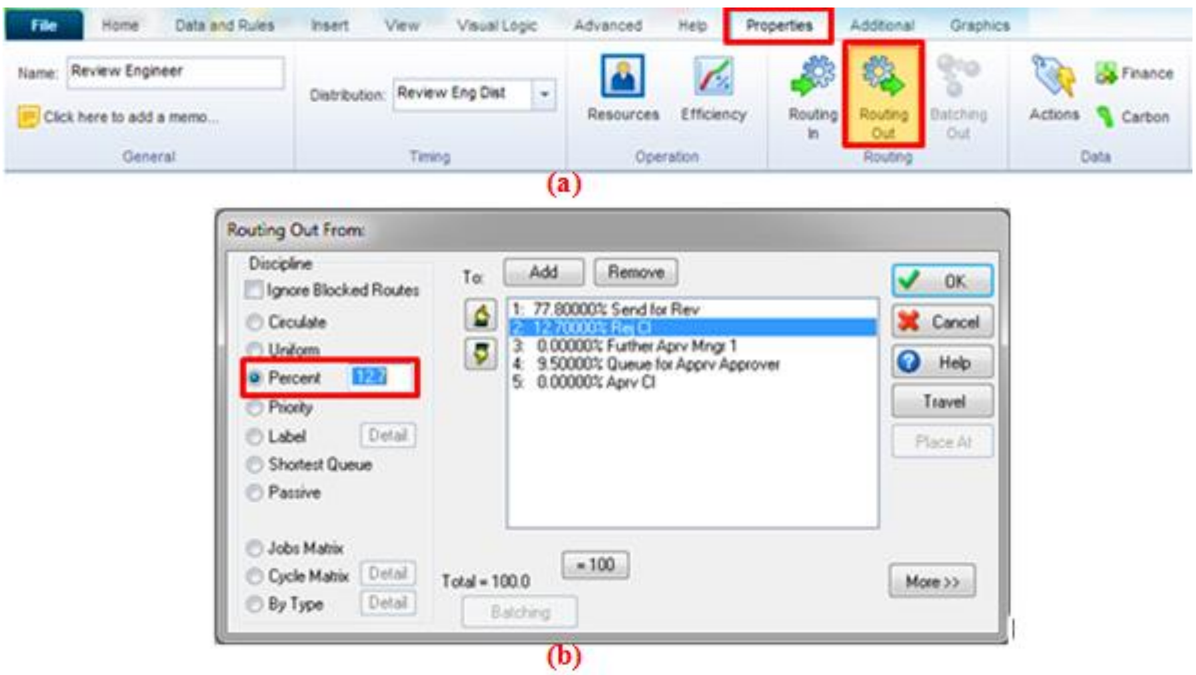


Figure 4-17: “Percent” for directions in Routing Out command of work centers

4.8.5 The Use of “Label” Command (Labelled Change Requests)

As stated before, in the change request workflow there were four types of change request document; Engineering, Vendor, Field, and Contract. To implement these four types of change request in Simul8, “Label” command was used. Four types of labels were defined and the change requests documents, upon entering at the Start Point, were labelled accordingly. Therefore, they were distinguishable from each other throughout the simulation process upon their entering to any activity centre. For instance, Figure 4-18 shows how the color-coded and labelled change requests are routing out from the dummy centre, “Dummy Verify details Dist” into their defined directions.

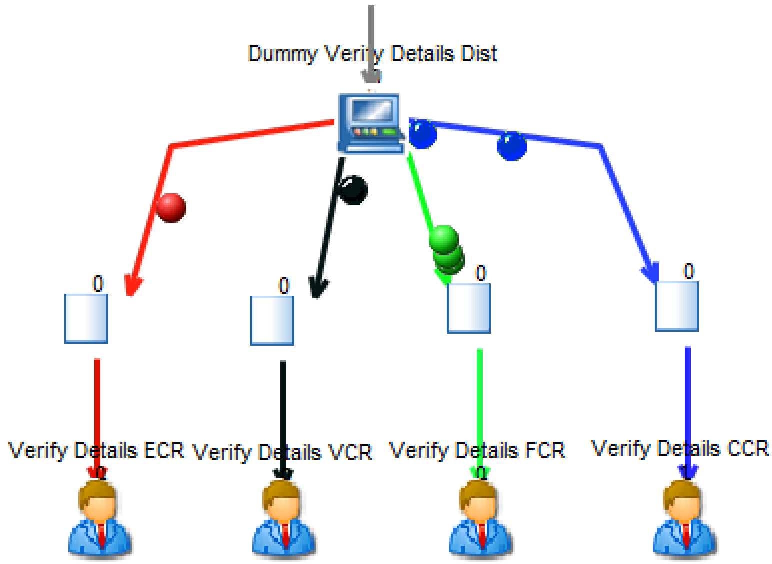


Figure 4-18: Change Requests Routing Out from the dummy centre “Dummy Verify Details Dist” according to the predefined labels

As stated before and the data analysis showed that, in “Review Participants” not all the reviewers would receive all types of change requests for review and evaluation. In other words, some reviewers were receiving all types of change requests (Engineering, Vendor, Field, and Contracts) whereas some only one type or two types of change requests (Field and Contracts). The use of Label command was the contributing factor to programming Simul8™ to follow this pattern. For example, in the “Review Participants”, the Engineering change requests, labelled “lbl_type 1” were being sent to the reviewers *1, 2, 4,5, 6* and *8* and Field change requests, labelled “lbl_type 3” to reviewers *2, 4, 5, 6,* and *19*. As seen, reviewers *8* and *19* were receiving “Engineering” and “Field” change requests respectively while the other reviewers were receiving both types.

4.9 Summary

This Chapter's focus was on data collection of a Canadian oil and gas megaproject, the development of a simulation model for the change request workflow of the project under consideration, and the challenges in data analysis and workflow simulation model development and the strategies used tackle these challenges. The sources of the data were the project database in Coreworx^{TM}, the research partner and the interviews with the project expert. The former was mainly used to capture the behavior of the "Generation Three" change request workflow executed in the project under consideration and the latter to gain proper information about the operation of "Generation One and Two" of change request workflows implemented prior to the "Generation Three". In the workflow implementation analysis, two points were observed. First, the human-based tasks remained intact in all implementations while some machine-based tasks were either added or eliminated to facilitate the change request process. Second, the machine-based tasks spent zero time with no queue in the change request process, whereas the waiting time and nominal working time the human-based tasks varied from a couple of seconds to a couple of hours. These two observations led to the development of both conceptual and simulation models of the change request workflow based solely on the human-based tasks. Another observation pertained to capurable and uncapturable times. The capturable times corresponded to the time stamps recorded in the database for each workflow instance passing any task of the workflow implementation. The uncapturable times corresponded to the time spent for negotiations, phone calls, and suchlike in the process of change request and was recorded neither in database nor in change logs. Although the inter-arrival time of change requests was exponential, the service times did not fit in any statistical distribution. To overcome this challenge, External distribution, which is the use of empirical data in the change request simulation model, was used. With the aid of Simul8 commands, the simulation model was developed. Next Chapter mainly focuses on the verification and the validation of this model.

Chapter 5
Validation and Verification of the Simulation Model

In Chapter four, based on the analysis of the change request workflow and the data of a Canadian oil and gas megaproject selected as the case study of this research, a simulation model was developed. This Chapter includes the verification and validation of this simulation model. To verify the simulation model, it is tested against the mathematical aspects (i.e.: inter-arrival rates of the actual change request process) calculated from the empirical data of the actual change request process, which used as a source of input data for the simulation model. Validation, on the other hand compares the validity of the output results of the simulation model with the results of the actual change request processes (Figure 5-1).

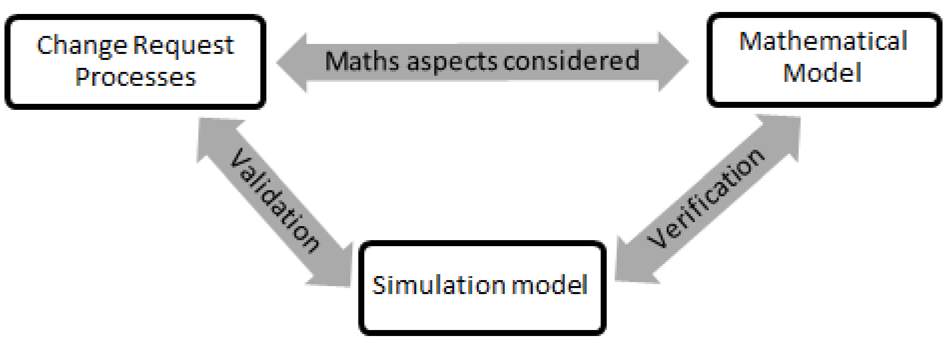


Figure 5-1: the Relation between the Verification and the Validation of a Simulation Model and the Actual Change Request Processes

5.1 Simulation Model Verification

In order to verify the structure of the model, throughout the simulation modelling process, the comments and feedback of 3 individuals who are the experts in the simulation area were used. These individuals are:

- David Wheatley: (The then Teaching Assistant of the course Discrete Event Simulation MSci 632, taken by the author in spring 2012 term, and the current lecturer at Wilfred Laurier University, Waterloo, Canada)
- Jim Holtman: Simulation expert and Consultant at Kroger with over 20 years of experience with Simul8^{TM}.
- Tony Smith: Business Operations Executive at Simul8^{TM} Corporation.

For a complicated simulation model like the change request workflow, the best strategy to accurately model the workflow in the simulation environment is to break down the workflow into segments. Then each segment should be modelled in the simulation environment based on the elements, activities (tasks) and the entity (Change request document) happening in that segment. This strategy proved to provide more controllability of the simulation model, less confusion on how the activity centres are linked together, and faster rectification and debugging when the simulation model malfunctioned.

5.1.1 The Verification of the Simulation Model's Inter-Arrival Time (IAT)

This Section verifies how many change requests are entering into the simulation model in the allotted time. In other words, the inter-arrival distribution of the actual workflow, as discussed before, is exponential with a Lambda (the rate parameter) based on the number of change requests and their arrival times. The simulation model should generate the same number of change requests or at least close enough to those of the actual workflow. Amongst four types of the change requests in all actual workflow implementations of OGP2, Engineering Change Request (ECR) was found to be the most frequent one, as shown in the following table:

Table 5-1: the number of change requests based on type in OGP2

Change Request Type	Number	Percent of Total
Engineering	41	41/72 = 57%
Vendor	26	26/72 = 36%
Field	2	2/72 = 3%
Contract	3	3/72 = 4%
Total	*72*	*100%*

A key point is that all of these change requests randomly enter to the workflow through one unique path. Figure 5-2 illustrates a sample of the change requests' arrival times (in hours) to the workflow. The timeline represents the total of the working hours (60 working hours per week) of all the workflow implementations that were in operation in OGP2. The timeline is not drawn to scale and the numbers in parentheses following the type of CRs indicate the arrival time (in hours) of that CR in the workflow.

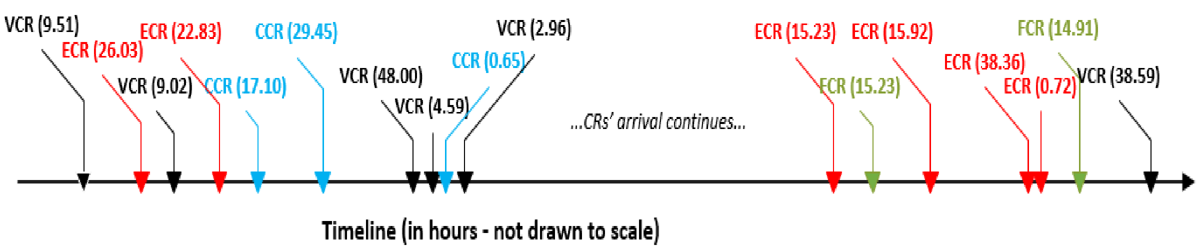


Figure 5-2: A Sample of Change requests' Arrival Times (in hours) to the CR Workflow

Although it seems correct to categorize the change requests based on their type and calculate their lambda based on their arrival times, this method resulted in a less accurate lambda calculation for those change requests, field and contract per se, whose number of arrivals is too few. This method also caused problems during the calculation of the running time of the simulation model. The running time was calculated from the difference between the arrival times of the first and the last change requests entering to the workflow, which were extracted from the "Created Date Time" column of the database table (see Table 4-1 in Chapter 4). When change requests were categorized based on their type, the running time would vary for each change request type. For instance, the running times for Engineering (Figure 5-3) and Vendor (Figure 5-4) Change Request types respectively, based on the data analysis, was gained from:

$$Running\ Time\ for\ ECRs = \ Last\ arrival\ date\ and\ time - first\ arrival\ date\ and\ time$$

$$= (\text{Thu } 9{,}1{,}2011\ 17{:}04{:}31) - (\text{Fri } 4{,}29{,}2011\ 6{:}07{:}21) = 1078.95 \text{ Working Hours}$$

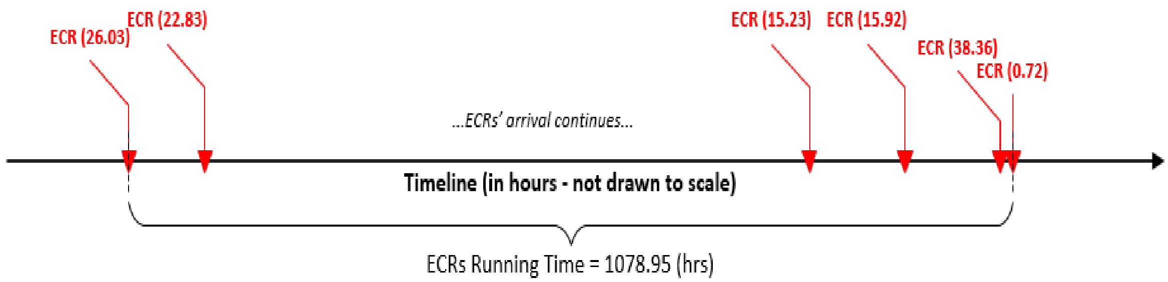


Figure 5-3: Running time for ECRs (A sample of 41 ECRs in OGP2)

$$Running\ Time\ for\ VCRs = \ Last\ arrival\ date\ and\ time - first\ arrival\ date\ and\ time$$

$$= (\text{Thu } 9{,}15{,}2011\ 7{:}38{:}09) - (\text{Wed } 4{,}13{,}2011\ 10{:}34{:}19) = 1329.06 \text{ Working Hours}$$

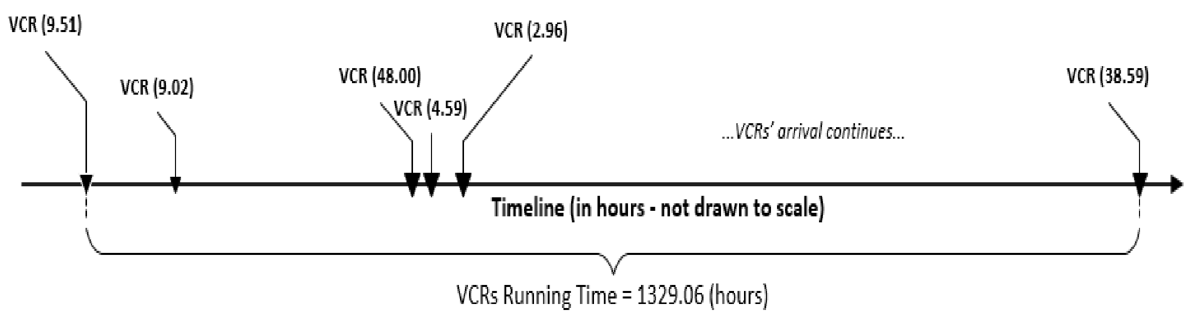


Figure 5-4: Running time for VCRs (A sample of 26 VCRs in OGP2)

Figure 5-3 and Figure 5-4: Running time for VCRs (A sample of 26 VCRs in OGP2)Figure 5-4 illustrate only a sample of 41 ECRs' and 26 VCRs' arrival times in OGP2. Due to defining one start point to generate the change requests in the simulation model, only one of the above times could be considered for the simulation running time. If 1078.95 hours was considered for the simulation running time, providing the lambda (λ_{ECR} = 0.039 from Table 4-8 in Chapter 4) is correct, only the number of Engineering Change Requests entering to the simulation was accurate and the number of Vendor Change Requests was not. This is because the running time and lambda are calculated based on only the number of ECRs and their arrival times in the workflow and not the number of VCRs.

This method, as the initial approach developed, led to an inaccurate number of change requests of each type arriving to the simulation model. In an alternative approach, the arrival times of *all* types of change requests of OGP2 were considered together. Therefore, the running time for the simulation model was based on a whole *time period* within which all types of change requests arrived in all workflow implementations. This time period was gained from the difference between the first Change Request's and the last Change Request's arrival times regardless of their type. Accordingly, one unique lambda ($\lambda_{\text{for all CRs}}$ = 0.053) was calculated (See Appendix I). As a result, an accurate number of change requests entering in the simulation model was obtained (See Table 5-2)

As discussed in Section 4.8.5 of previous Chapter, to generate four different types of change request from one Start Point, the use of "Label" is critical. To use "Label", in Simul8^{TM} environment select the Start Point and open "Actions" dialog box. Click on "Add a Label to Change" and select the predefined label (see "lbl_type" highlighted in Figure 5-5(a)) to add it to the "Change:" slot. Select the radio button "Set to:" and click to open "Label Value" dialog box (Figure 5-5(a)). From the "Distribution:" dropdown list select "Arrival by Type", as the predefined external distribution (Figure 5-5(b)). (The use of External Distribution as one of the Simul8^{TM}'s features was discussed in Section 4.6.2 and Figure 4-9 in Chapter 4).

Monte Carlo simulation was used in the spreadsheet column allocated to the "Arrival By Type" distribution, to generate change requests' types with same percentage as generated in the actual workflow in OGP2 as tabulated in the last column of Table 5-1. The running time of the simulation, based on the first and the last change request entering to the workflow, was 1329.06 hours

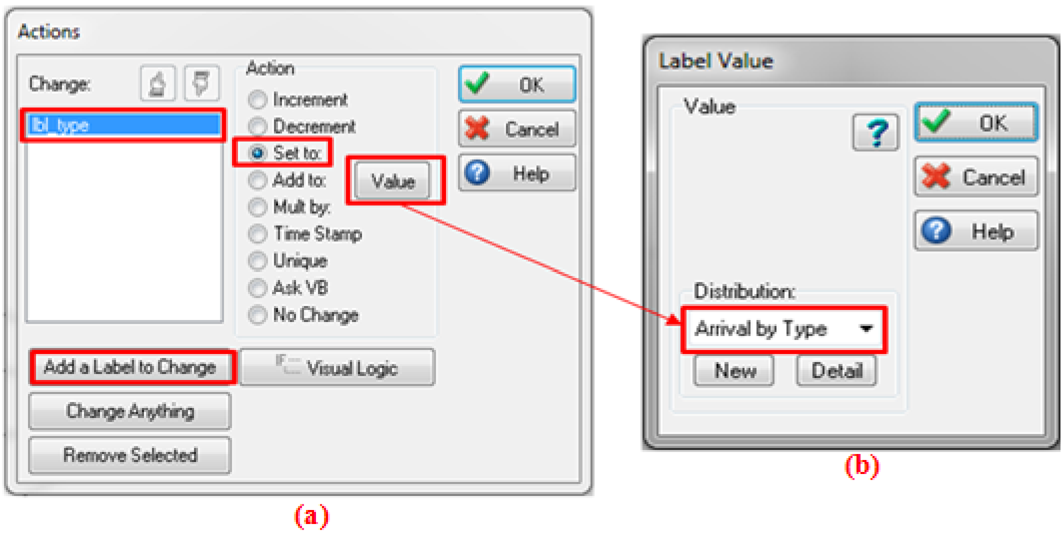


Figure 5-5: The use of "Label" and "External Distribution" to generate change request types at the Start Point

To verify the inter-arrivals times of change requests, the CR's inter-arrival simulation model (Figure 5-6(b)) was run for one trial with the running time set to 1329.06 hours (Figure 5-6(a)). This resulted in 82 change requests in total which is almost 14% higher than 72, the number of change requests generated in the actual workflow. The segregated results with one trial are shown in the middle column of Table 5-2. To get more accurate results, 6 trials, as recommended by Simul8^{TM}'s Trial Calculator set to 5% confidence limit, were executed. Figure 5-6(c) shows the segregated results of each change request type at the End Point based on these 6 trials. As seen from Table 5-2, the total number of ECRs, as the most frequent change request generated, is the same in both the actual workflow and the simulation model run with 6 trials (last column of the table). Even for VCR, FCR, and CCR the results are close if not the same. Therefore, it can be concluded that the simulation model based on inter-arrival of change requests is verified. The next Section's focus is on the validation of the model.

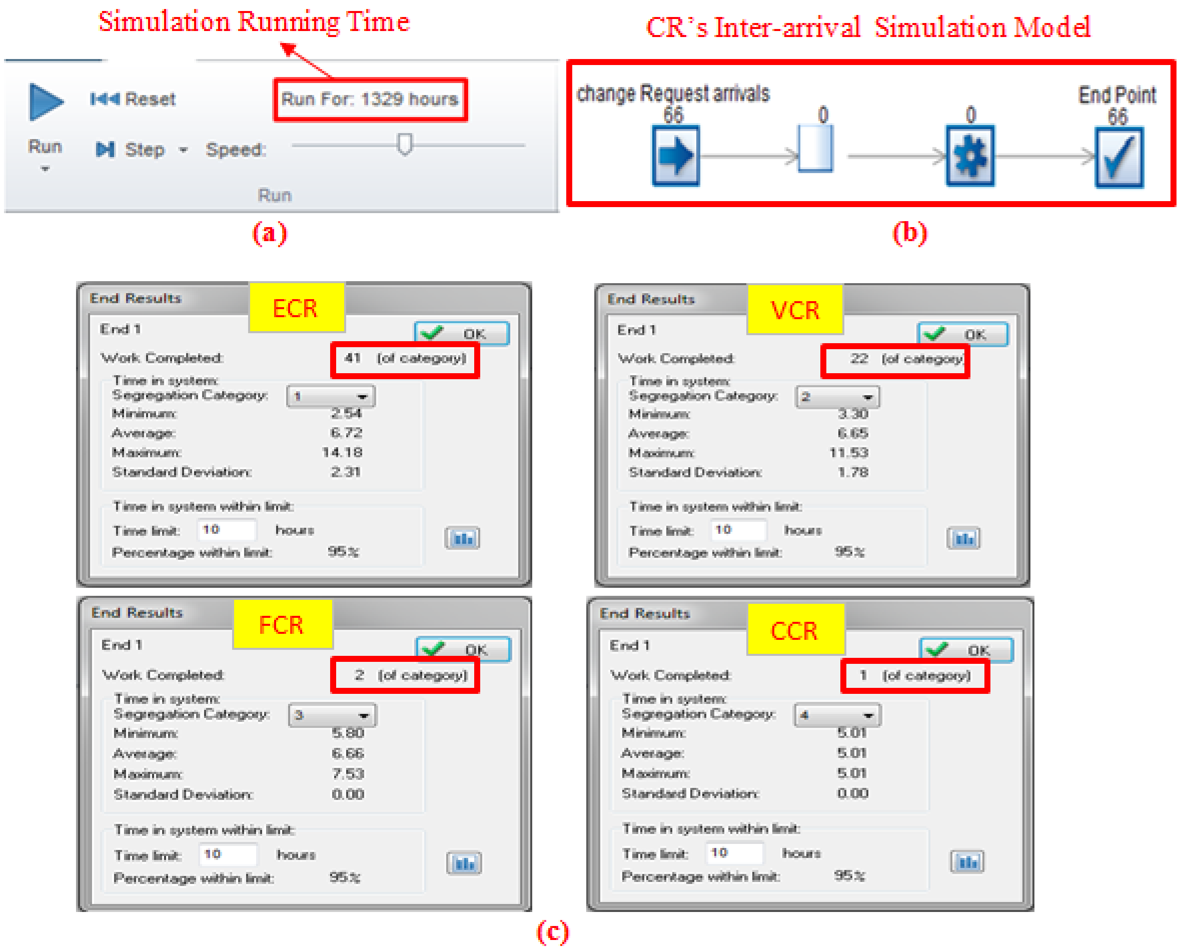


Figure 5-6: CR's Inter-arrival Simulation Model and the Segregated Results for each CR type

Table 5-2: The verification of the Inter-arrivals for change requests

Change Request Type	Number of change requests in OGP2 (Data Analysis of the workflow, $\lambda = 0.0534$)	Number of change requests in the CR's Inter-arrival Simulation model, $\lambda = 0.0534$	
		One trial	6 Trials (recommended by Simul8 Trial Calculator)
Engineering	41	47	41
Vendor	26	27	22
Field	2	5	2
Contract	3	3	1
Total	*72*	*82*	*66*

5.2 Validation of the Simulation Model

Validation and verification of a model are related. However, the following factors have been considered to validate the simulation model of the change request workflow.

5.2.1 Morphology (Checking the Graphics) of the Simulation Model

In order to make sure that all details of the actual workflow are considered in the simulation model, as the first step of the validation, the morphology of the simulation model was compared with that of the actual workflow. The simulation model and the actual workflow are not identical. The reason is that the machine-based activities of the actual workflow graphics, except the automated gateways, were not considered in the simulation model. Also, some activities, like dummy distributors, were added in the simulation model. The graphical validation of the simulation model was also checked and confirmed with David Wheatley, a Simul8™ expert.

5.2.2 Visually Testing the Simulation Model

Table 5-3 shows the color-coded paths and color-coded dots representing the four types of change requests along with their description. As another validating factor of the simulation model, the visual observation of each type of change request was required to check whether or not the change requests of each type (color-coded dots) properly follow their exclusive color-coded paths between the activity centres from the Start Point to the End Point of the simulation model. The color-coding method in the simulation model is very helpful not only to distinguish the types of change requests from each other, but also to help the reader better understand how the simulation model of the change request workflow has been constructed (Figure 4-10 and Figure 4-18 in Chapter 4) and works.

Table 5-3: Color coding for change request types and their path in the simulation model

Paths	Dots	Description
		Exclusive paths for Engineering CRs represented by red dots
		Exclusive paths for Vendor CRs represented by black dots
		Exclusive paths for Field CRs represented by green dots
		Exclusive paths for Contract CRs represented by blue dots
		General paths for all four types of CRs

The Simul8™ interface enables the user to control the speed of the simulation model while running. The running process was slowed down to carefully track the moves of the color-coded dots, randomly selected, from the start point to the end point of the simulation model. This visual testing was also conducted a couple of times and checked with David Wheatley, a Simul8™ expert. Figure 4-18 in Chapter 4 shows the flow of the dots in their own paths in "Verify Details" task of the simulation model.

5.2.3 A Comparison between the Number of Change Requests of Completed Simulation Workflow and the Actual Workflow

Table 5-2 demonstrates that the number of change requests of each type in the inter-arrival simulation model is almost the same as the actual workflow data analysis of OGP2. The same comparison is required between the segregated results of the end points of the *completed* simulation model and the number of change requests of each type from the actual workflow data analysis of OGP2. If the results are the same or close, then the simulation model is validated.

The running time for the whole simulation model was 1656 hours, calculated based on the time between the arrival date and time of first change request and the completion date and time of the last change request gained from data analysis of the actual workflow. Logically speaking, the time period of the whole actual workflow was larger than that of the inter-arrival time; 1329 hours, because for one thing; all change requests were the completed ones (the incomplete change requests were considered as the outliers and taken out) and also these complete change requests took some amount of time, no matter how long upon their arrival, to get completed. Thus, the completion time period was always larger than the inter-arrival period of the change requests. The results of the simulation running time are tabulated in Table 5-4. The table shows that the results are close, especially for the rejected change requests. The insufficient number of change requests from the Field and Contract types (from the data analysis) may raise questions about the accuracy of the simulation model for these two types. However, the simulation results for Engineering and Vendor types were close enough to the real ones to validate the model at that point. Note that these results were from only one run of a trial of the simulation model. More trials typically lead to more accuracy. The number of trials required for the simulation running and the related confidence interval are covered in Section 5.2.5.

Table 5-4: a comparison between actual workflow and a simulation model run for the number of change requests

Change Request Type	Number of change requests in OGP2 from the data analysis of the actual workflow		Number of change requests from the segregated results of the end points of the simulation model	
	Rejected	Approved	Rejected	Approved
Engineering	14	23	13	14
Vendor	4	20	3	10
Field	1	1	1	1
Contract	0	1	0	2
Total	19	45	17	27

5.2.4 The Average Service Time

Another parameter contributing to the simulation model's validation is the workflow instances' average duration or the average time that change requests have spent in the system (simulation model) from the start point to the end point. This average time then should be compared with the average time of the change requests in the actual workflow. Figure 5-7 depicts the average service time of change requests in both "Approved Close Out" (Figure 5-7a) and "Rejected Close Out" (Figure 5-7b) end points respectively. The results were compared with the average service time of rejected change requests and that of the approved ones calculated from the data analysis of the actual workflow.

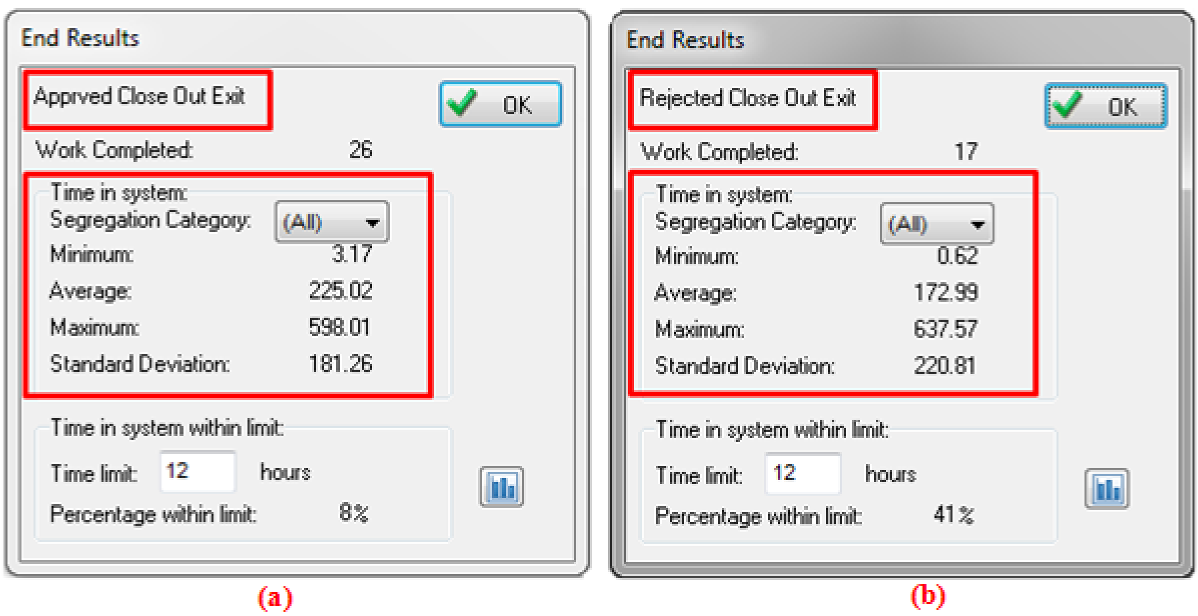


Figure 5-7: Service Time of (a) Approved and (b) Rejected CRs

To validate the model based on the average service time parameter, the average service time of the simulation was compared with the average service time of the actual workflow. The results are tabulated in Table 5-5 :

Table 5-5: a Comparison of Average Service Time between the Actual Workflow and the Simulation Results

	Average service time for the rejected CRs	Average service time for the approved CRs	Total average service time (Rejected +Approved)
Actual Workflow	158 hours	247 hours	221 hours
Simulation Model	172 hours	225 hours	$\frac{172 \times 17 + 225 \times 26}{17 + 26} = 204\ hours$

As shown in the table, the results were close enough to initially validate the model. However, since the results are from one run of a trial of the simulation model, the standard deviations; 181.26 and 220.81 for the Service time of Approved CRs and the service time of Rejected CRs, (see Figures 5-7a and 5-7b) were too broad. Therefore, several runs were required, as explained in the following Section, to reduce the standard deviation and increase the confidence in the model validation.

5.2.5 Number of Trials and Run

To get more accurate and more reliable results for the validation of the simulation model, it is required to rerun the simulation model many times. Simul8^{TM}'s definition of a trial in simulation is: [http://simul8.com/support/help/doku.php?id=model_building_basics:trial, last accessed: 15/March/2014]

> *A trial or experiment is a series of runs of the simulation model, performed with the same settings for all parameters other than "random number". As the simulation intended to resemble real life scenarios, it is important to run a simulation more than once.*

Based on this definition, the simulation model of the workflow was executed for many times with the running period set to1656 hours (see 5.2.3). The number of runs of a trial is critical, because it directly affects the accuracy of the simulation results. To determine the number of runs required, “Calculate Required Number of Runs” was used. This option is accessible through “Run Trial” in the Home tab in the Simul8^{TM} (Figure 5-8).

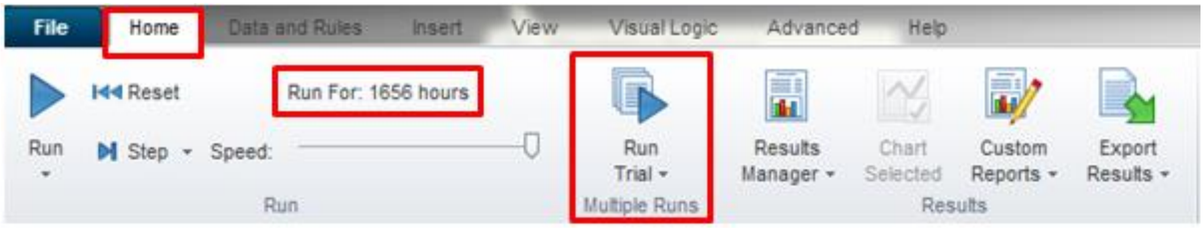


Figure 5-8: Access to the "Number of Trials" option

Through this option, the required precision of the confidence interval can be selected. For the simulation model of the change request 95% confidence interval was considered. The Key Performance Indicators (KPIs) to meet this required precision should be selected. Four KPIs were considered in the simulation model. These KPIs are:

1. Approved Close Out Exit: Number Completed

2. Approved Close Out Exit: Average Time in System

3. Rejected Close Out Exit: Number Completed

4. Rejected Close Out Exit: Average Time in System

The 1st and the 3rd KPIs are concerned with the number of the rejected and approved change requests and the 2nd and 4th KPIs with the average service time for the rejected and approved change requests at their end points.

Repetitively executing the simulation model for 1656 hours, Simul8^{TM} narrows down the confidence limits (standard deviation gets closer) towards the mean and calculates the number of runs for the highlighted KPIs (Figure 5-9). Considering this process, the recommended number of runs was 323. The final results for all of the aforesaid KPIs are projected in Figure 5-10.

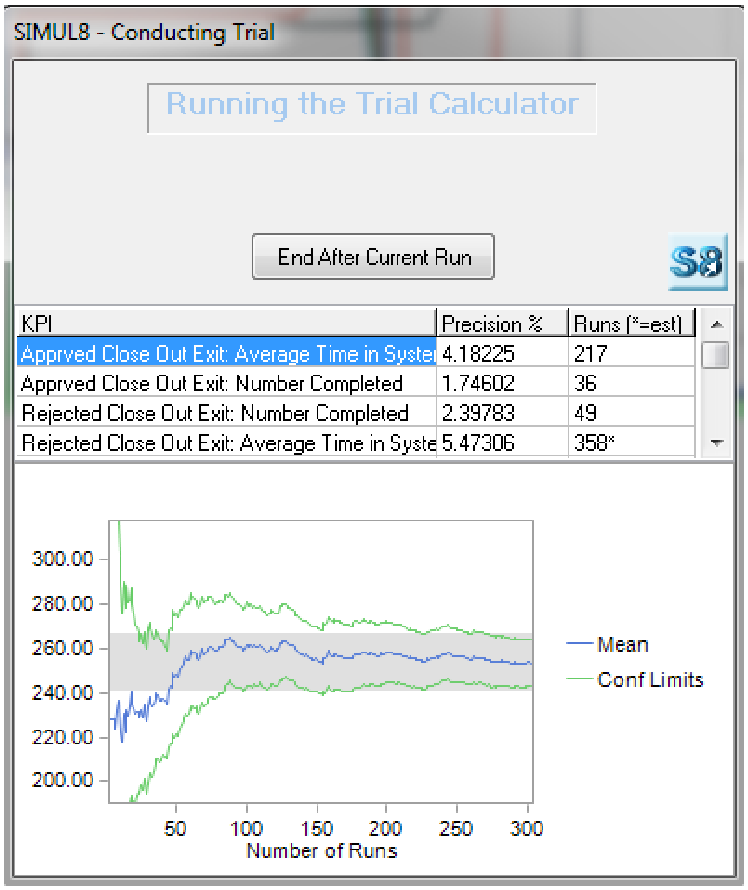


Figure 5-9: Confidence Interval and Number of runs for the KPIs

Figure 5-10: The results of running the simulation for 323 runs

Table 5-6 shows the summary of the results for the simulation validation. When compared, the number and the average service time of approved and rejected change requests in the simulation model is close to the empirical data of the actual workflow. Therefore, the simulation model is considered validated.

Table 5-6: Summary of the results for the simulation model validation

No of CRs	in the Simulation Model	*Approved*	*41*
		Rejected	20
	In Actual Workflow (OGP2 Data Analysis)	*Approved*	*45*
		Rejected	19
Average Service Time	in the Simulation Model	*Approved*	*227*
		Rejected	147
	in Actual Workflow (OGP2 Data Analysis)	*Approved*	*247*
		Rejected	158

5.3 Summary

In this Chapter the verification and the validation of the simulation model were explained. The validated simulation model of change request workflow lays the foundation to meet the thesis's first objective which is the comparison between three generations of change management. As stated before, in the Canadian oil and gas megaproject (case study), the process of a change request for human-based tasks remained unchanged regardless of when and what generation of the change request process had been used in the project. Therefore, the validated simulation model, developed based on the human-based tasks can be used to compare the three generations of change requests. To do this, a scenario for each generation of change request process is defined. Then, the validated simulation model based on these scenarios is executed and the results will be compared. Since the validated simulation model of change request workflow remains the same, even a segment of it can be selected instead of the whole simulation model. The next Chapter's focus is on the running of the validated model for the scenarios developed for three generations of change request processes and the analysis of outputs.

Chapter 6

Running the Validated Model and Output Data Analysis

As shown in the previous Chapter the simulation model of the change request workflow is verified and validated as per the real model and its empirical data. To meet the objectives of this research, in this Chapter, a simplified simulation model of the change request workflow is being tested for three generations of change request processes, defined in Chapter two, and the results are compared as per the metrics defined in Chapter three which are workflow average duration and compliance. As for the continuous improvement, the workflow implementations of the change request automated workflow are also compared based on time, compliance, and steady state.

6.1 Simplified Simulation Model for the Three Generations of Change Request Process

The validated model of change request workflow was tested for each of the three generations of change request processes respectively. In order to have an “apples to apples” comparison, a scenario in which all the detailed tasks of the change order process from the initiation to completion of the change requests was considered for each generation. In order to make sure no task is overlooked, the details of the tasks of the scenarios, especially for generation one and two of change request processes, were checked with the project experts.

6.1.1 Scenario 1: Generation One Process

Let us consider that the change requests are being issued by vendors or contractors on average every hour exponentially distributed. Considering that change request issuers are based in a remote area (located in different provinces of Canada or states of the USA), 15 to 20 change requests are batched by the prime contractor and mailed out to the owner’s headquarters for evaluation. This can be done by a courier such as "Canada Post Priority™" which takes one day (24 hours: next working day) for parcel delivery. (http://www.canadapost.ca/web/business/mailing-and-shipping.page#canada, Canadapost website; last accessed April/24th/2014).

Upon receiving the batch, the receptionist spends on average 2 minutes normally distributed to do the "date and document ID stamp". Then the registered change requests are physically taken to the coordinator who is based in another department. This transaction takes on average 20 minutes. It is important to know that the project experts, when asked about the locations of the departments, confirmed that in a Canadian oil and gas megaproject (the research case study) *the change request document transfer was from one department to another but in the same building. For some high value change requests, however, this physical document transfer was from one building to another both located in the same city*. Upon receiving the change requests, the coordinator does a 3-step task. He/she first spends on average 2 minutes normally distributed on each change request form to *verify the details* in terms of the issuer's document endorsement (signature and stamp), reference number, and attachments. If faulty, the CR is sent back to the receptionist who informs the issuer to fetch the batch of faulty CRs for modification. If passed, the CR is *photocopied* and *archived*. The photocopying and archiving are the 2nd step of the coordinator's job which takes two minutes and five minutes respectively on average normally distributed for each CR. As the 3rd step, the coordinator takes 20 minutes on average to *distribute* the CRs amongst the responsible engineers to evaluate. The responsible engineer also does a 3-step task. First, he/she spends on average 5 minutes normally distributed on each CR to see if it is delivered to the right person or not. If delivered to the wrong person, the CR is sent back to the coordinator for redistribution. In the second step, the responsible engineer fully evaluates the CR in terms of cost impact, schedule impact, details and comments. The time period in this stage considerably varies from a couple of minutes (10 minutes) to a couple of hours (5 hours). Thus a bimodal distribution is considered. If found incomplete or ambiguous, the CR is *returned for information* by the receptionist to the issuer. If not, it goes to the next engineer who repeats the same tasks. Figure (6-1) shows Generation One's process and Table (6-1) shows the details of roles and responsibilities and also the tasks in the process. A point to clarify is that throughout the process, the staff may be unavailable (busy with some other tasks) to immediately work on the change request delivered which causes delay in the change request process. This issue, albeit true in reality as discussed in Sections 4.2 and 4.4.3 in Chapter 4, is neglected in all three scenarios.

6.1.2 Scenario 2: Generation Two Process

Now let us consider the change request process from the Generation One switched to the Generation Two. Like the Generation One change request process, the change requests are being issued by vendors or contractors on average every hour exponentially distributed. Considering that the change request issuers are based in remote area (located in different provinces of Canada or states of the US of A), 15 to 20 change requests are batched and mailed out to the owner's headquarters for evaluation. This can be done by a courier such as "Canada Post Express" which takes one day (24 hours: next working day) for parcel delivery (http://www.canadapost.ca/web/business/mailing-and-shipping.page#canada, Canadapost website; last accessed April/24th/2014). This part of the Generation Two process is the same as that of the Generation One process. But the rest of the process is changed to the Generation Two process, since the use of the Internet, emails, and Computers comes in. Therefore, it can be also called a mix of Generation One and Generation Two processes.

Upon receiving the batch, the receptionist scans the CRs and sends them by email, as a means of communication, to the coordinator. If required to do so, an electronic ID code is manually entered by the receptionist. The receptionist emails the PDF format (scanned) of the CR to the coordinator doing a two-step job on the email sent. The whole task takes around a couple of minutes on average per CR, normally distributed.

In the 1st step of the task, if the coordinator finds the CR is not attached to the email sent (the receptionist's mistake), as a rework, he/she emails back the receptionist to re-email the missing attachment. This 1st step of the task would take less than a minute on average normally distributed. However, there should be time delays, probably for hours on the re-mailing, as the receptionist maybe working on something else when the request is received. As the 2nd step, he/she opens the PDF file to *verify the details* in terms of the issuer's endorsement (signature and stamp), attachments, reference number of the CR, etc. If faulty, the CR is emailed back to the receptionist to notify the contractor on the incomplete areas of the CR. If complete, the CR, with proper notes, is electronically forwarded to the responsible engineer. The coordinator does the same task as he/she does in the Generation One process, therefore the average time, 2 minutes, for the "verify details" task in the Generation One process is applied in here. When compared between the Generation One and Generation Two processes, the coordinator's tasks; photocopying and archiving in addition to physical distribution of the CRs are eliminated.

The responsible engineer does a 2-step task upon receiving the CR. As the first step, he checks to see if the CR is forwarded to the right person or not. If not, he notifies the coordinator to re-email the CR to the right person. In here, there can be some hours-long delay due to the engineer's unavailability or their busyness with some other tasks. If yes, he then may start to evaluate the CR. Again, this task is identical in both Generation One and Generation Two processes, therefore the time average of 5 minutes does apply in here. In the 2nd step of the task, or "full evaluation", the responsible engineer in detail evaluates the CR in terms of cost and schedule impact, details, and comments. Like the Generation One process, the time period in this stage considerably varies from a couple of minutes (10 minutes) to a couple of hours (5 hours). Thus, a bimodal distribution is considered. If found incomplete or ambiguous, the CR, is *returned for information* by the receptionist to the issuer. If not, it goes to the next engineer who repeats the same tasks.

6.1.3 Scenario 3: Generation Three Process

In this scenario, let us assume that the whole process is now automated. The CRs are still being issued on every hour exponentially distributed but they would be directly sent as a change request draft, a standard electronic form, through an automated workflow implementation to the owner's office. Of course, the sender of the change request draft may spend on average 5 minutes normally distributed to prepare the draft prior to sending it.

The coordinator who receives the change request electronic form does only a one-step task; seeing the draft complete, he/she forwards it to the right person through the workflow implementation guided by the workflow engine. Finding it faulty, he/she sends back to the sender for correction. This task, as the data analysis of the previous Chapter shows and also validated is on average 5 minutes. The responsible engineer, who receives the change request, also does a one-step task. He/she fully evaluates it in terms of cost and schedule impact, attachments, details and comments. In an integrated automated process like the Generation Three, the responsible engineer is able to directly inform the sender, should he have the CR *returned for information.* This evaluation time, as mentioned in the aforesaid processes, varies from 10 minutes for the evaluation of the majority of the CRs to 5 hours for some, as validated in the previous Chapter. Thus, a bimodal distribution is considered. If found "good to go", the CR is sent through the automated workflow implementation to the next engineer who repeats the same task.

In all scenarios above, the probability of the process stoppage due to the malfunction of the electronic devices (scanners and photocopy machines used by the staff) is ignored. It is also considered that the staff is well trained individuals to work with the devices and the state of the art IT.

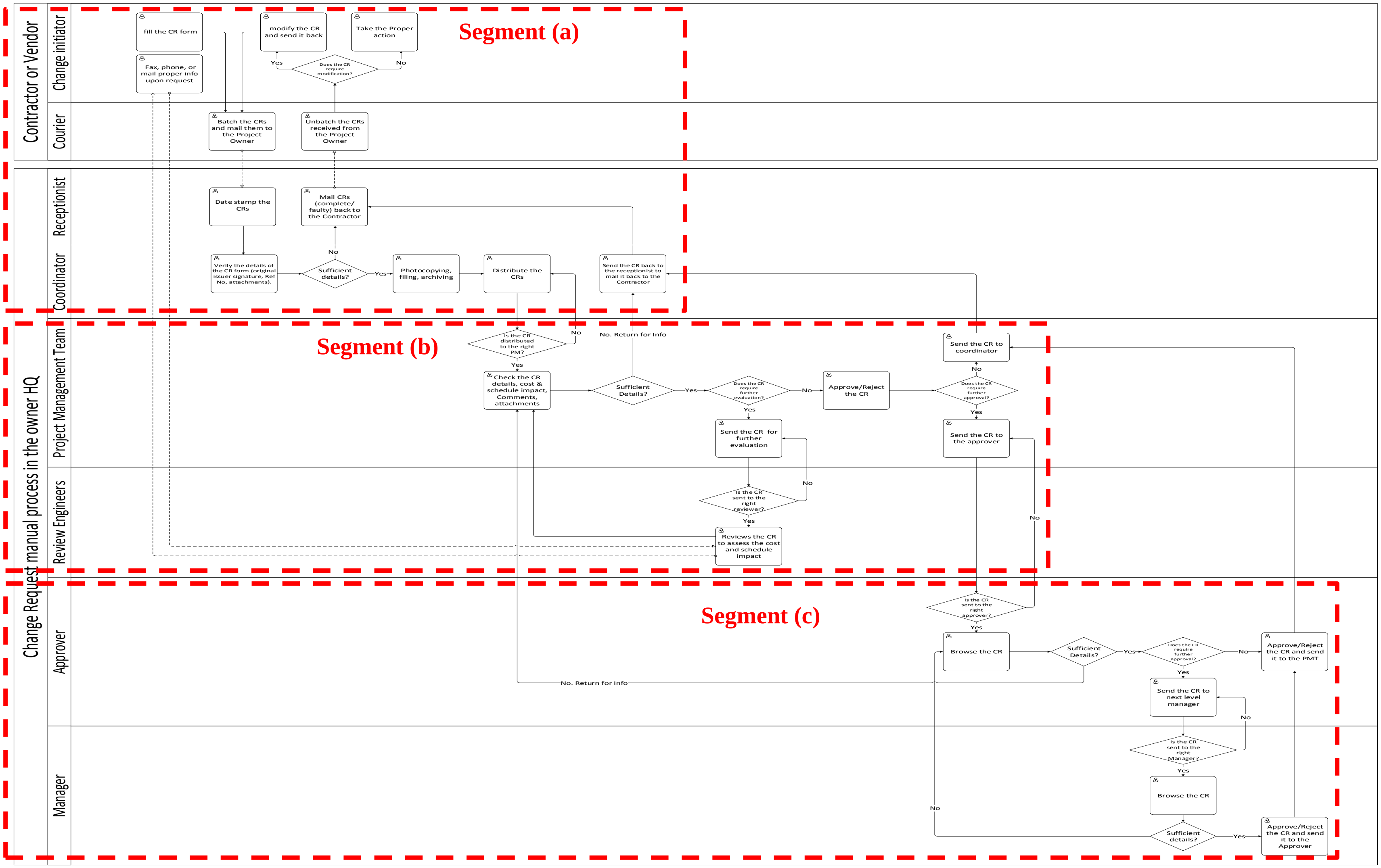


Figure 6-1: Roles, responsibilities, and tasks in Generation One and Generation Two change request processes used in Case Study

Table 6-1: The details of the Generation One and Generation Two processes

	Role	Responsibility	Activity
Contractor Or Vendor	Change initiator	Initiating a change	Fill the CR form
			Send the CRs Batch to Courier
			Fax, phone, or mail proper info upon request
			Modify the faulty CR and sent it back
			Take the proper action upon getting the approved/rejected CR
	Courier	Circulating the CRs between the owner & contractor	Take the CR batch to the Owner HQ receptionist (time based on the distance)
Change Request manual process in the Owner's HQ	Receptionist	Reception of the CR batch	Date stamp the CRs received
			physically take the CRs to the coordinator office (time based on distance)
			Mail the CRs (Complete/Faulty) back to the Contractor/Vendor
	Coordinator	Verification and distribution of CRs	Verify the details of the CR form (original issuer signature and stamp, Ref No, attachments)
			Photocopying, filing and archiving
			Physically take the CRs to the Project Management Team (time based on distance)
			physically take the CRs back to the receptionist to mail back to the contractor/vendor
	Project Management Team	Evaluation and distribution of the CRs	Check the CR for the Cost and Schedule impact, comments, and attachments
			send the CR for further evaluation, if required
			physically take the CR to the review Engineer for further evaluation (time based on Distance)
			directly approve or reject CRs and send them back to the coordinator
			physically take the CR to the higher approver/manager for further approval/rejection (time based on Distance)
	Approver	Evaluation of the CR	Browse the CR to approve/Reject it
			physically take the CR to the higher Manager for more approval/rejection(time based on distance)
			send the CR back to the PMT after approval or rejection
	Manager	Evaluation of the CR	Browse the CR to approve/reject it
			send the CR back to the approver

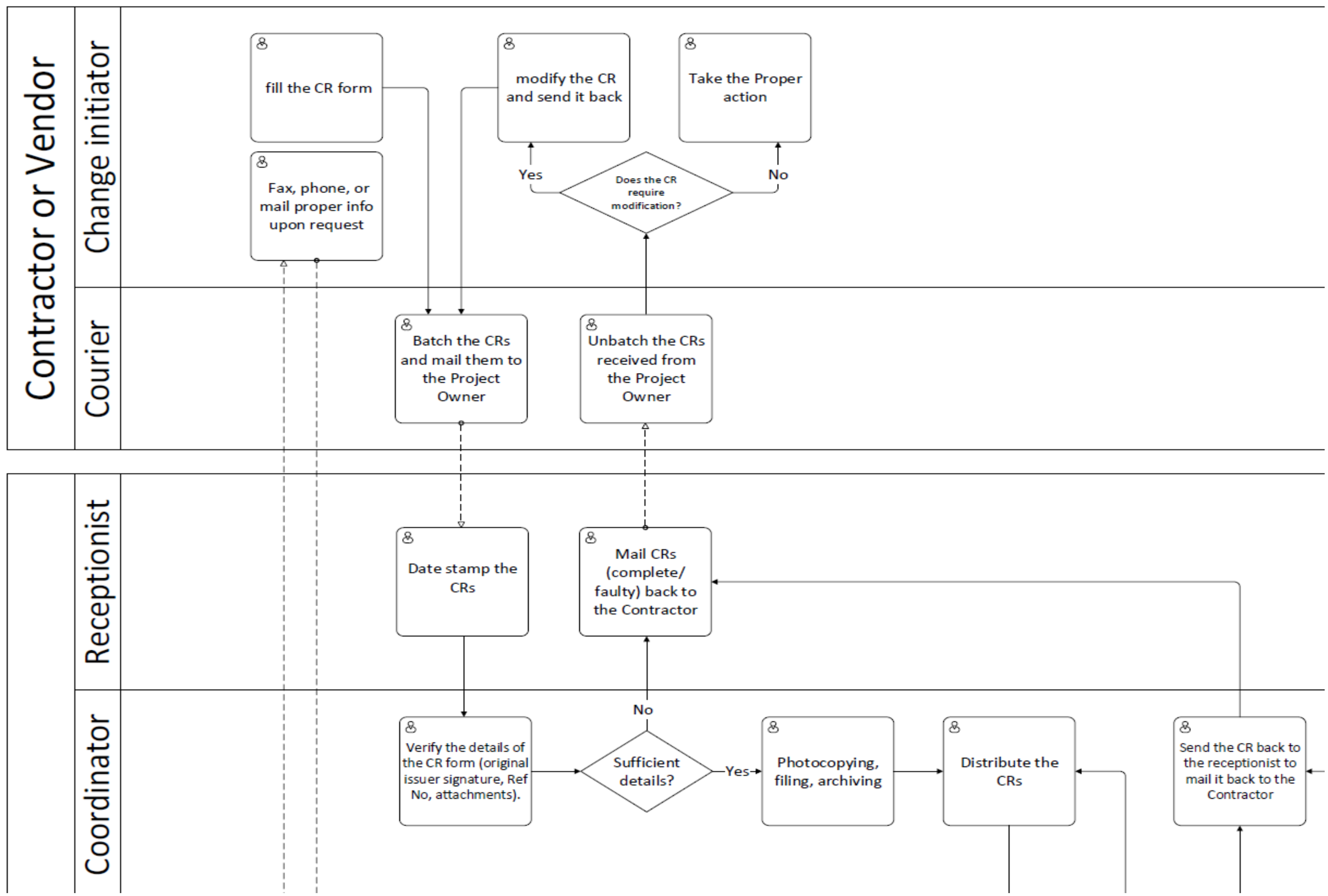


Figure 6-2: Magnified Segment (a) of the Generation One and Two Change Request Process of Case Study shown in Figure 6-1

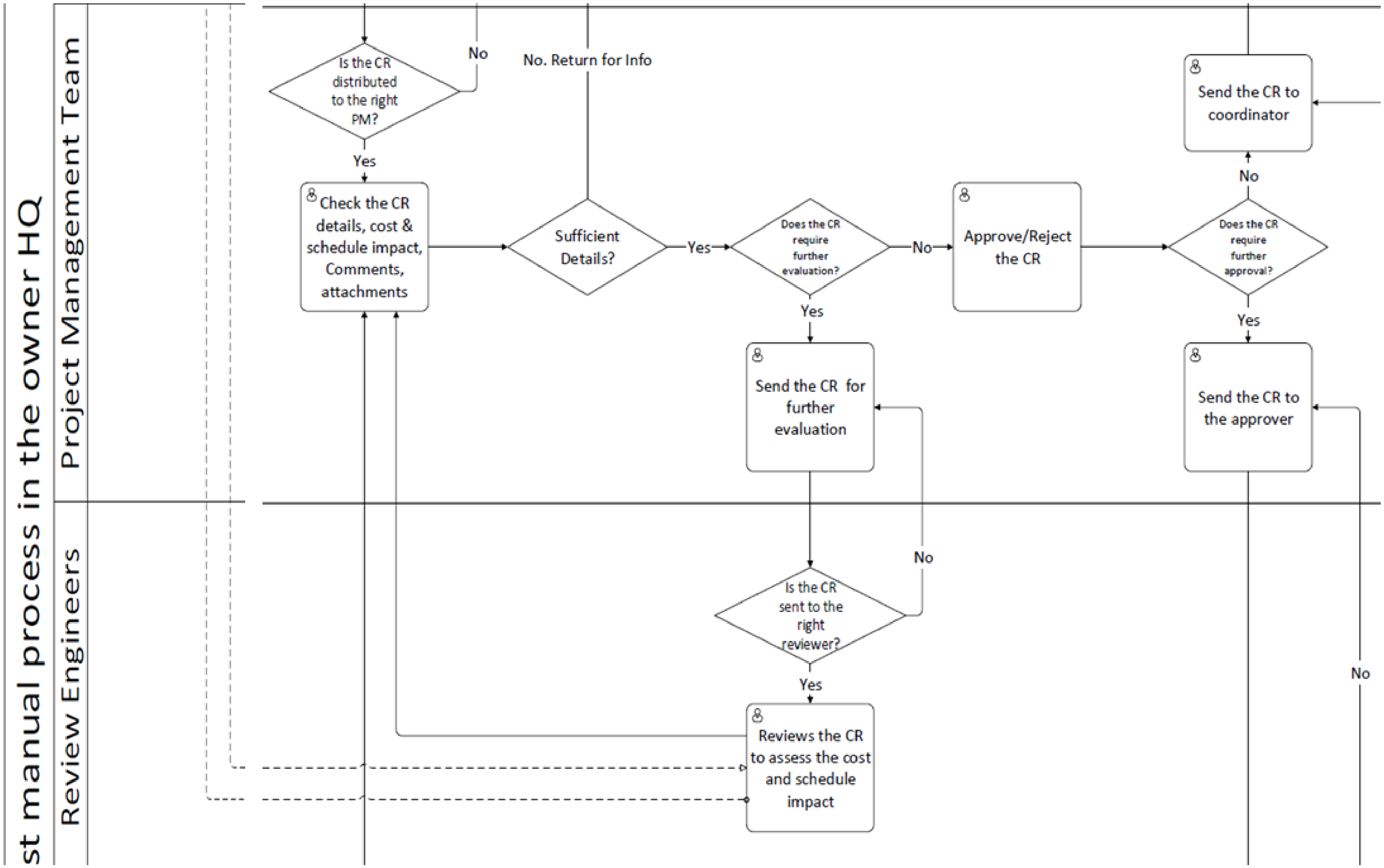


Figure 6-3: Magnified Segment (b) of the Generation One and Two Change Request Process of Case Study shown in Figure 6-1

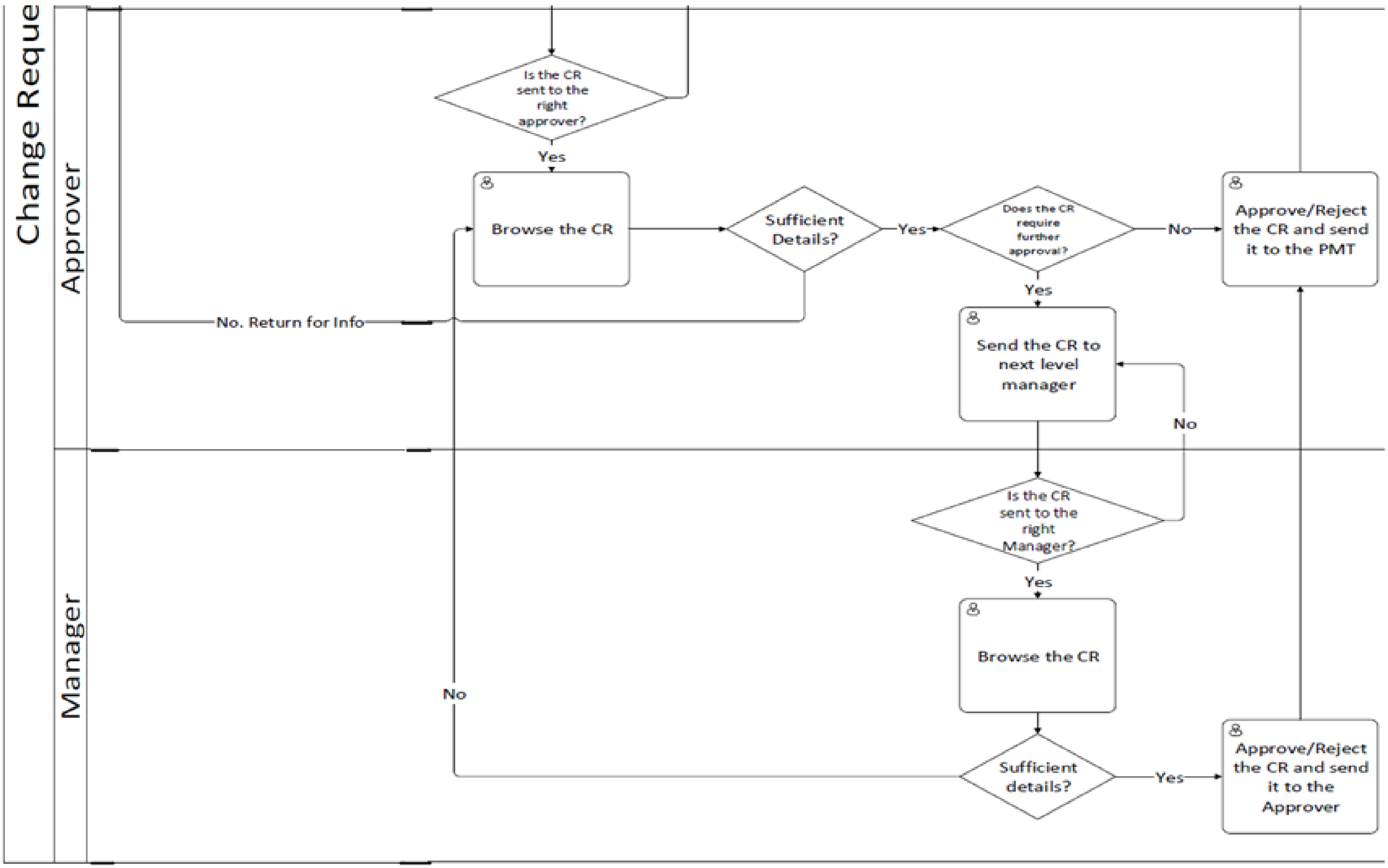


Figure 6-4: Magnified Segment (c) of the Generation One and Two Change Request Process of Case Study shown in Figure 6-1

6.2 Running the Scenarios' Simulation Models and comparing the Outputs

6.2.1 Running the Simulation Models of the Three Scenarios

The three scenarios were simulated in Simul8^{TM}. Figure 6-5, Figure 6-6, and Figure 6-7 respectively show the simulation model of each Generation of Change request processes. To better understand and compare the behavior of the three simulation models they are designed to run beside each other (Figure 6-8). Visually compared, the processes showed how the human-based tasks are either eliminated or replaced by machine-based tasks, as the project moves from the Generation One and Two processes to the Generation Three process (see also Figure 6-9, Figure 6-10, and Figure 6-11). This point should be reiterated that this research does not observe and include the behavior of the machine-based tasks, since their processing time would barely exceed a couple of seconds which is negligible and the probability of their failure in the Generation Three (automated) process is ignored as well.

In Figure (6-5) and Figure (6-6), the thick black lines represent the physical change request transfer from one Activity (work) centre to another. The grey lines, in the Generation One process, represent the physical transfer of the change requests from one activity centre (task) to another but to be done with the same resource (project team member). The grey lines in the Generation Two and Generation Three processes represent the electronic transfer of the change requests, the time period of which is close to zero.

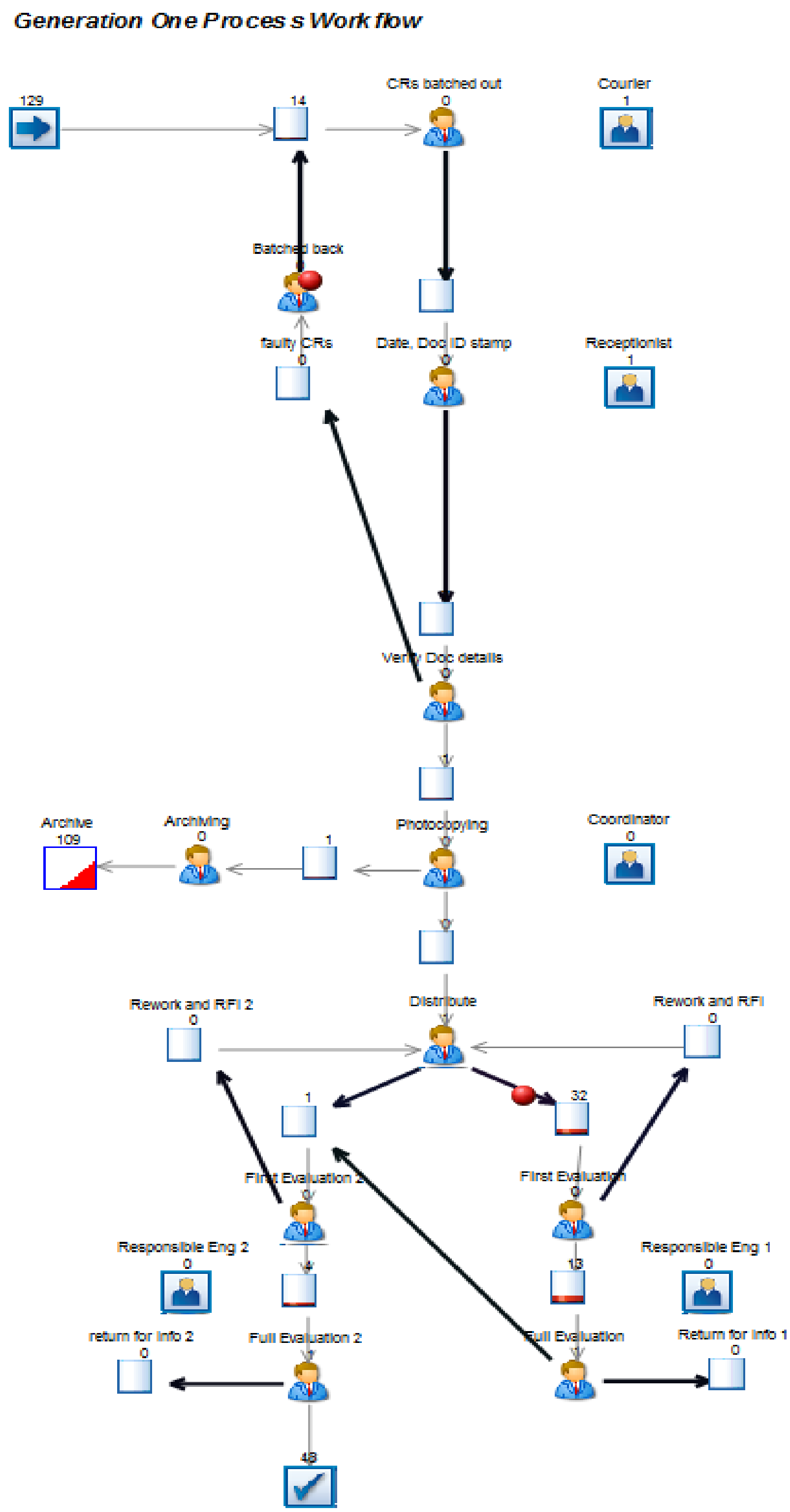


Figure 6-5: Generation One Process Workflow

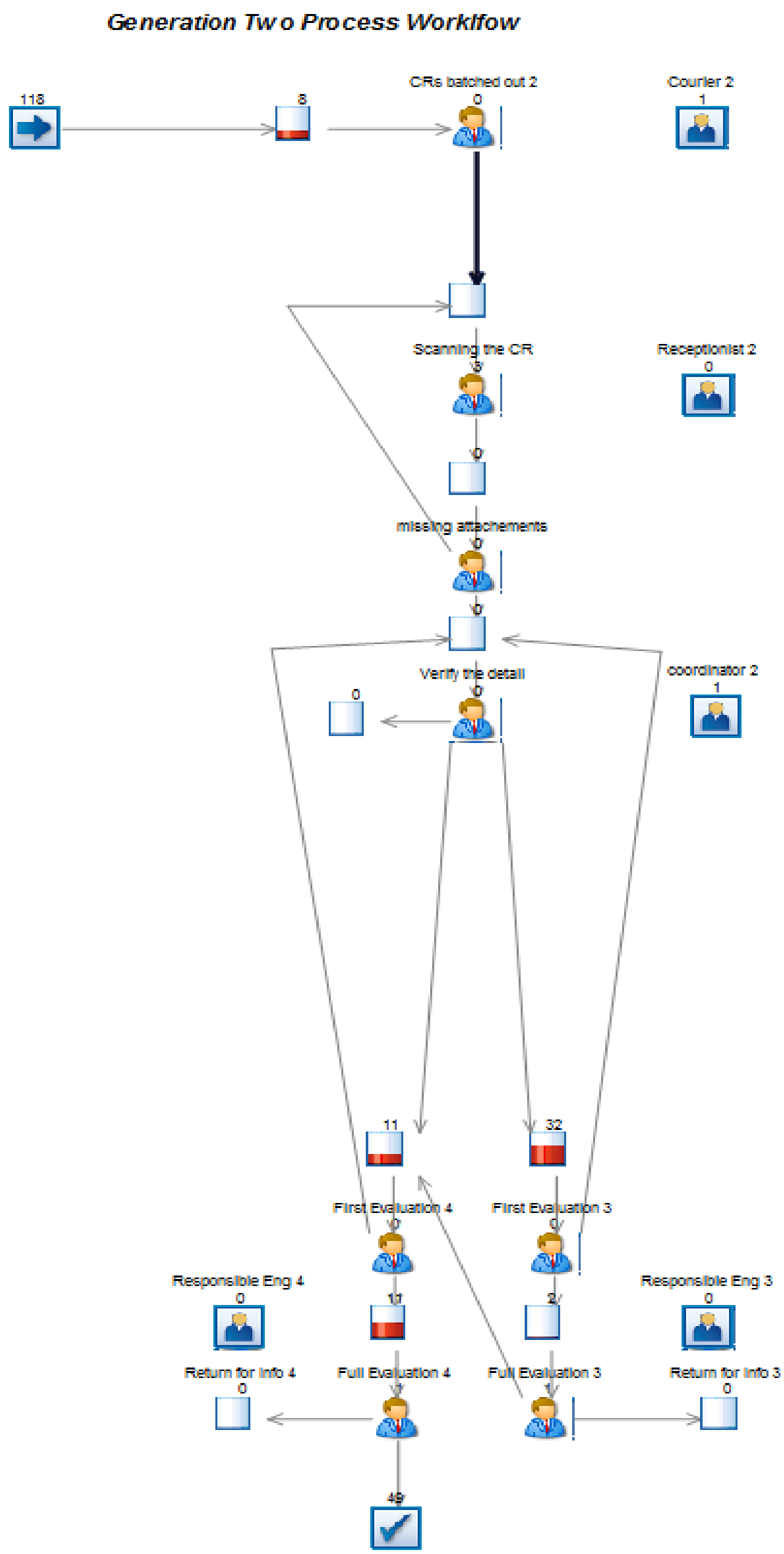


Figure 6-6: Generation Two Process Workflow

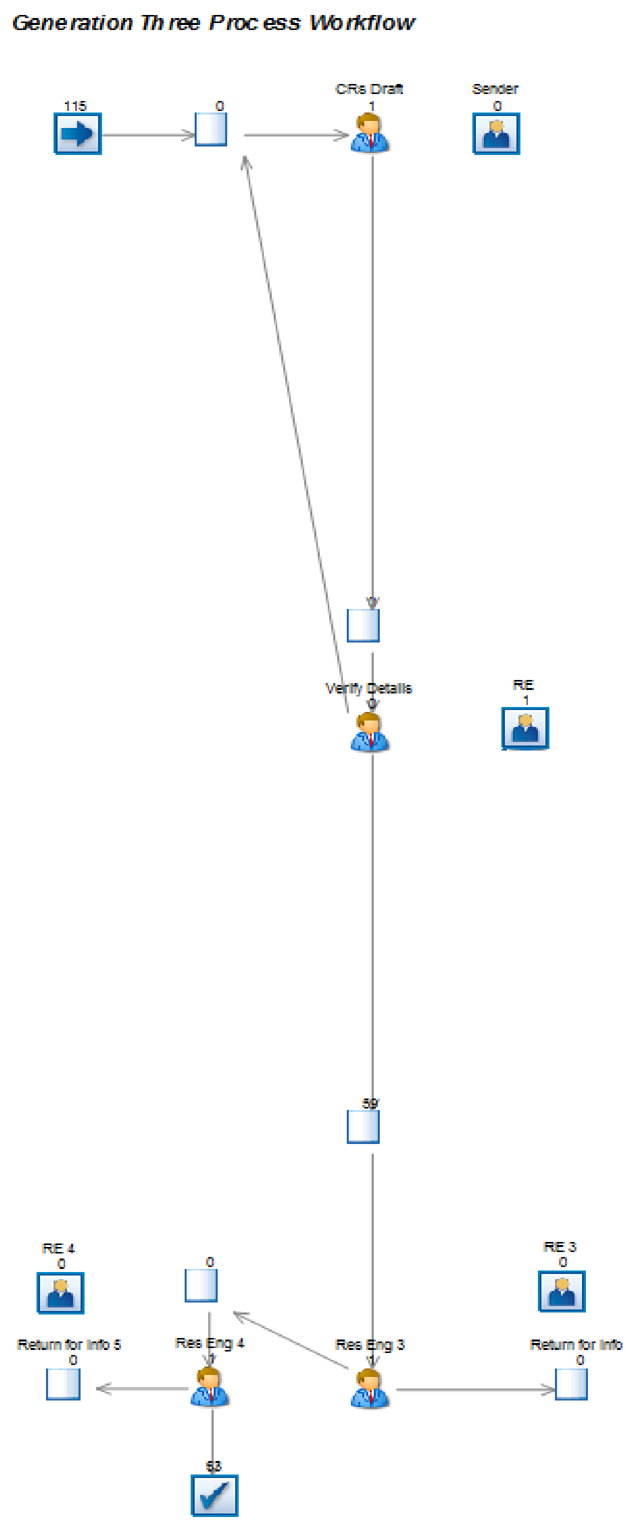


Figure 6-7: Generation Three Process Workflow

In Figure 6-8 the simulation models are divided into three segments; segment (a), segment (b) and segment (c) as magnified in Figure 6-9, Figure 6-10, and Figure 6-11 respectively. Each segment shows what task and resource is either minimized or eliminated as the change request process moves from the Generation One and Generation Two to the Generation Three. For instance, in Figure 6-9 two resources along with their tasks (the “courier” doing “CR’s batched out” and batched back” in the Generation One Process Workflow and the “receptionist” doing “Date, Doc ID Stamp” in the Generation One and “Scanning the CR” in Generation Two) are eliminated in the Generation Three. Because, as explained in the scenarios above, the “Change Request Draft” can be filled and directly sent by the “Sender” to the “Responsible Engineer” doing the “Verify Details”. As Figure 6-10 shows, “verify Doc details”, “photocopying”, “archiving”, and “distribute” as the responsibilities of the “coordinator” in the Generation One Process Workflow are reduced to “Verify Details”. The “Verify Details” task remains in the Generation Three Process Workflow but due to the use of workflow engine, the change request will be sent to the right person whereas, in the Generation Two the change request may be sent back to the coordinator due to the wrong delivery by the coordinator to the Responsible Engineer, as the receiver. In other words, the change request redelivery, defined as rework due to the human mistake is eliminated in the Generation Three Process Workflow while it is likely in the Generation Two Process Workflow. Figure 6-11 shows how the “First Evaluation” task, which is done with the “Responsible Engineer”, is eliminated when the Change Request Process shifts from the Generation One and Two to the Generation Three. As stated in the above scenarios, “First Evaluation” is a task in which a “Responsible Engineer” checks to see whether or not the change request is delivered to the right person. In other word, the rework of the change request wrong delivery becomes clear in this task. The “Return For Information” remains the same in all three processes. Because, unlike the “rework”, “Return For Information” is concerned with unclear or insufficient information given by a project team member to the best of their knowledge about a change request. Therefore, it is sent back for clarification which in turn may require negotiation.

The above explanation about each segment of the workflow may justify the results gained when the simulation models were in parallel executed. The charts and the explanation of these results are reflected in Section 6.2.2. The details about the simulation running time and the number of runs are outlined in the next paragraph.

The simulation model was executed for 160 hours as the running time for 100 runs, as recommended by the “Trial Calculator” feature in Simul8^{TM} to have the results within 95% confidence intervals. To compare the outputs of the simulation models, three Key Performance Indicators (KPIs) were set in Simul8^{TM}. These KPIs are:

- The Number of CRs for each workflow entering to the system,
- The average time in the system,
- The number of CRs completed.

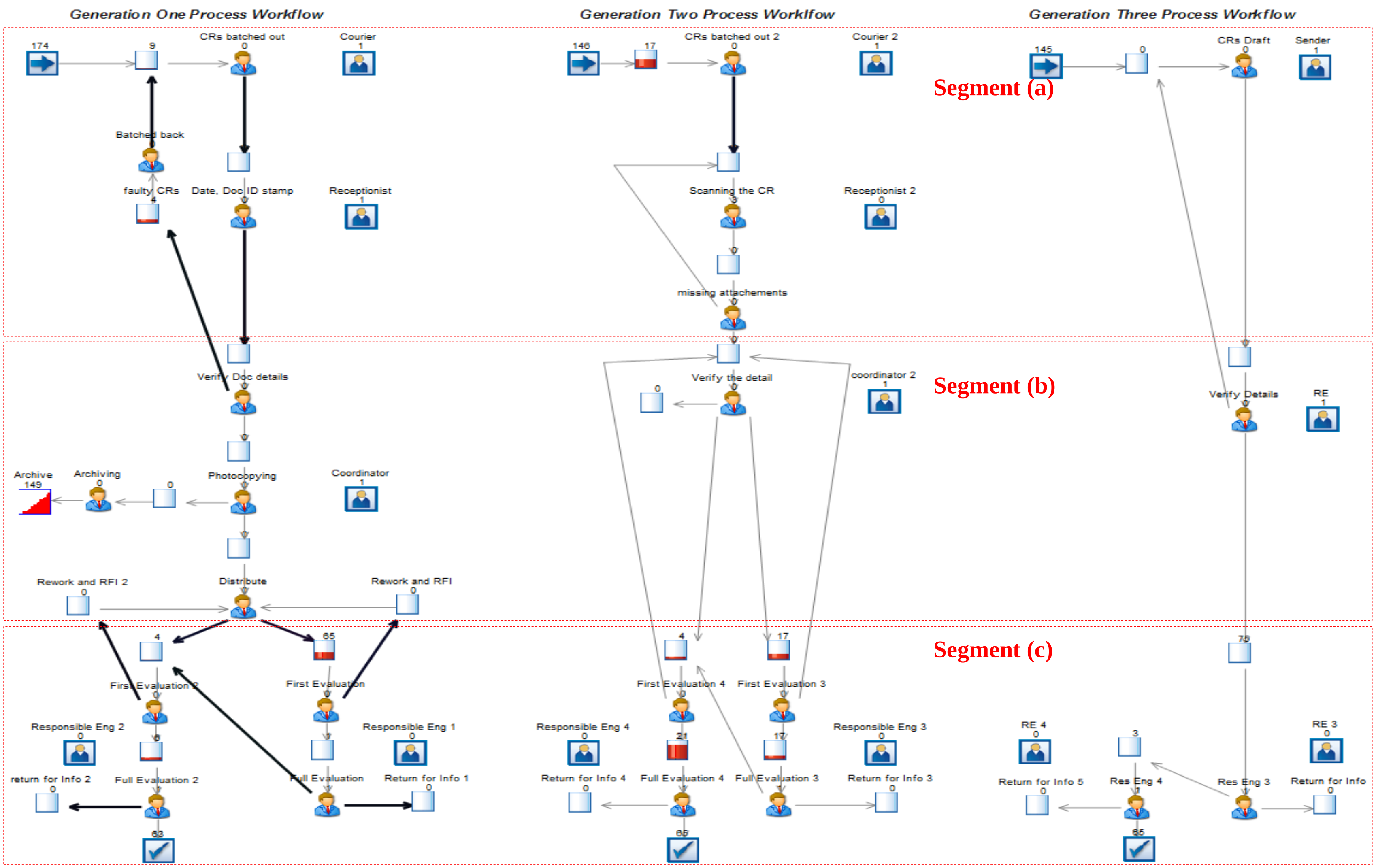


Figure 6-8: Simplified workflows in Generation One, Two, and Three of Change Management processes

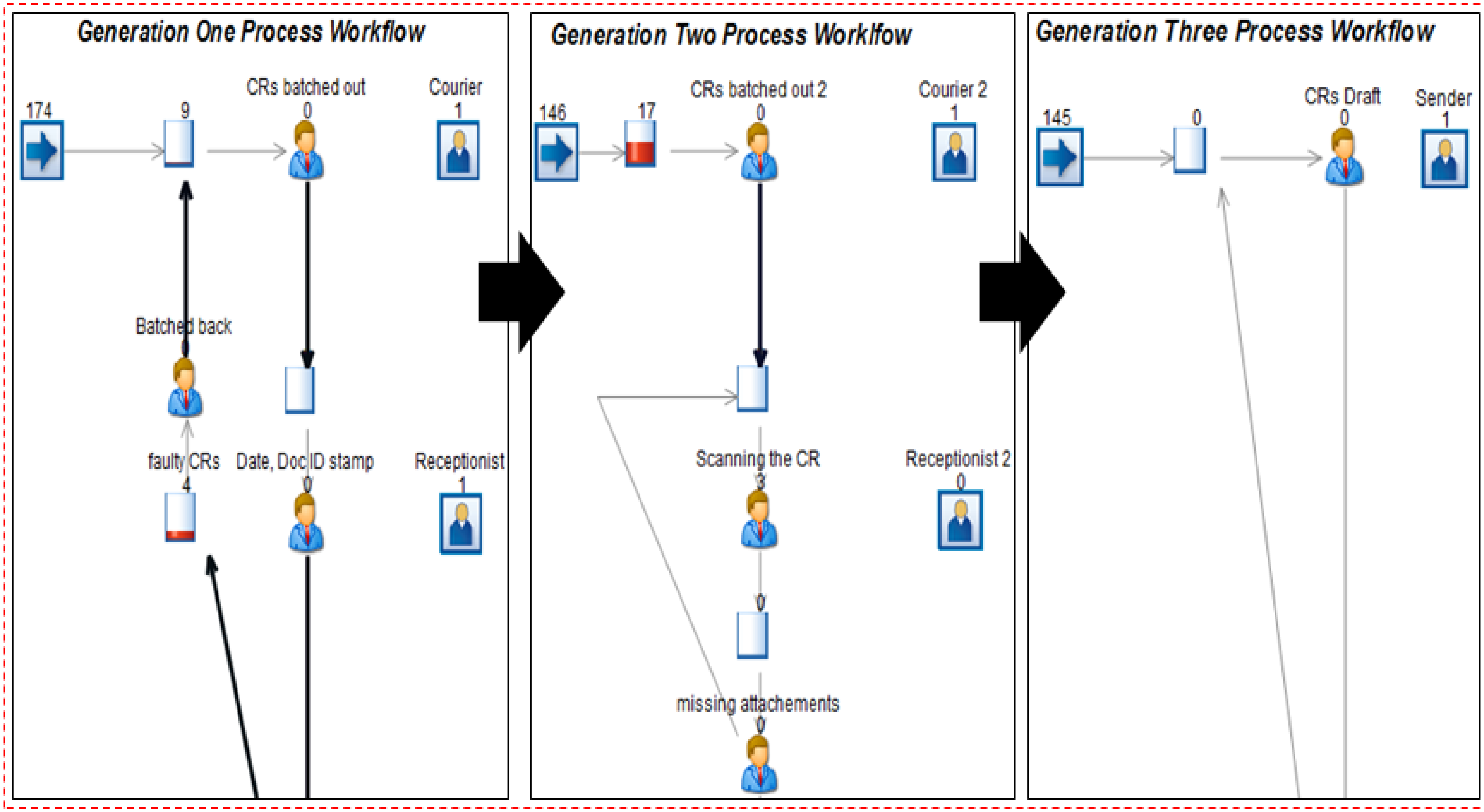


Figure 6-9: Segment (a) of the three workflows

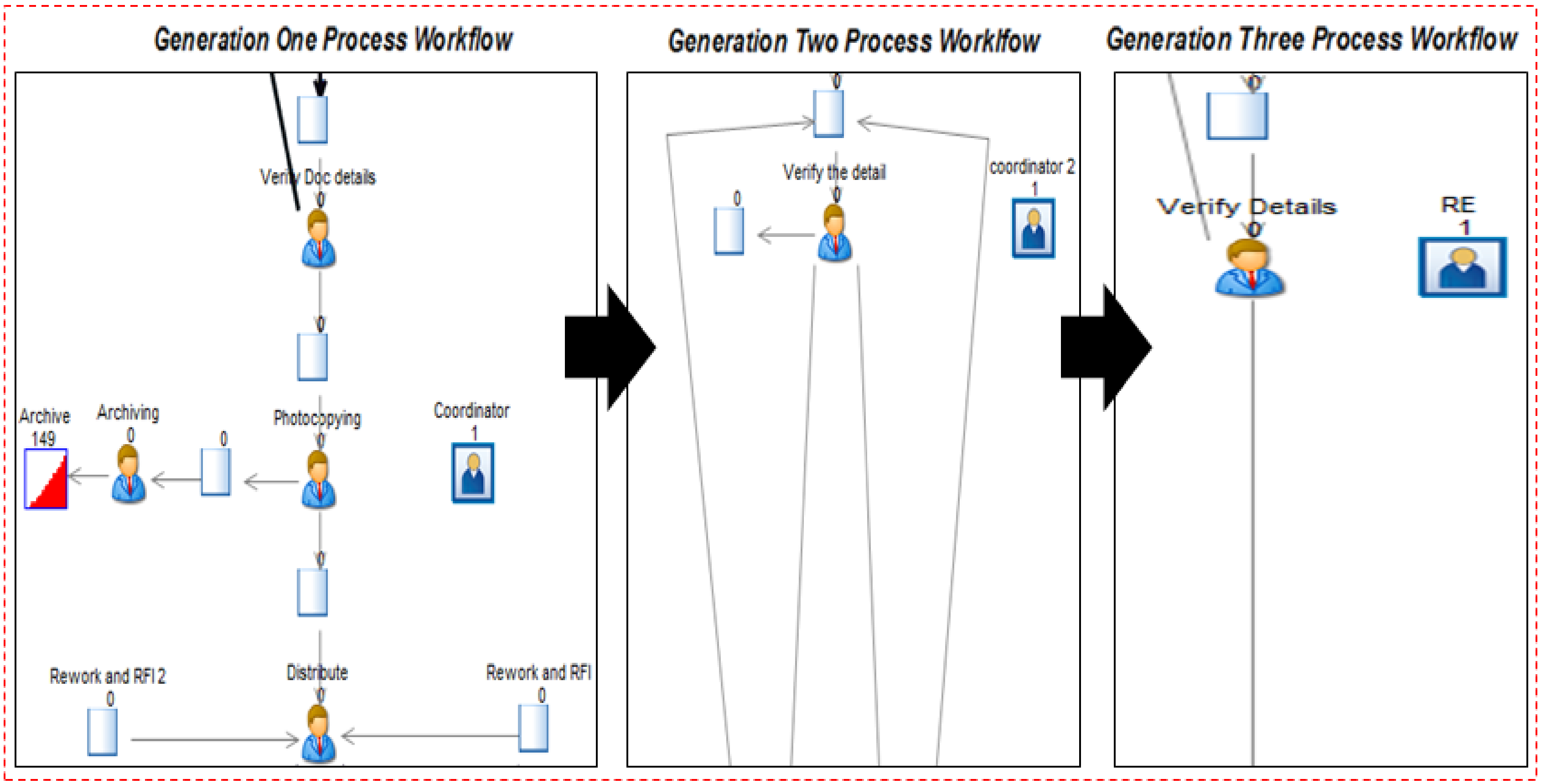


Figure 6-10: Segment (b) of the three workflows

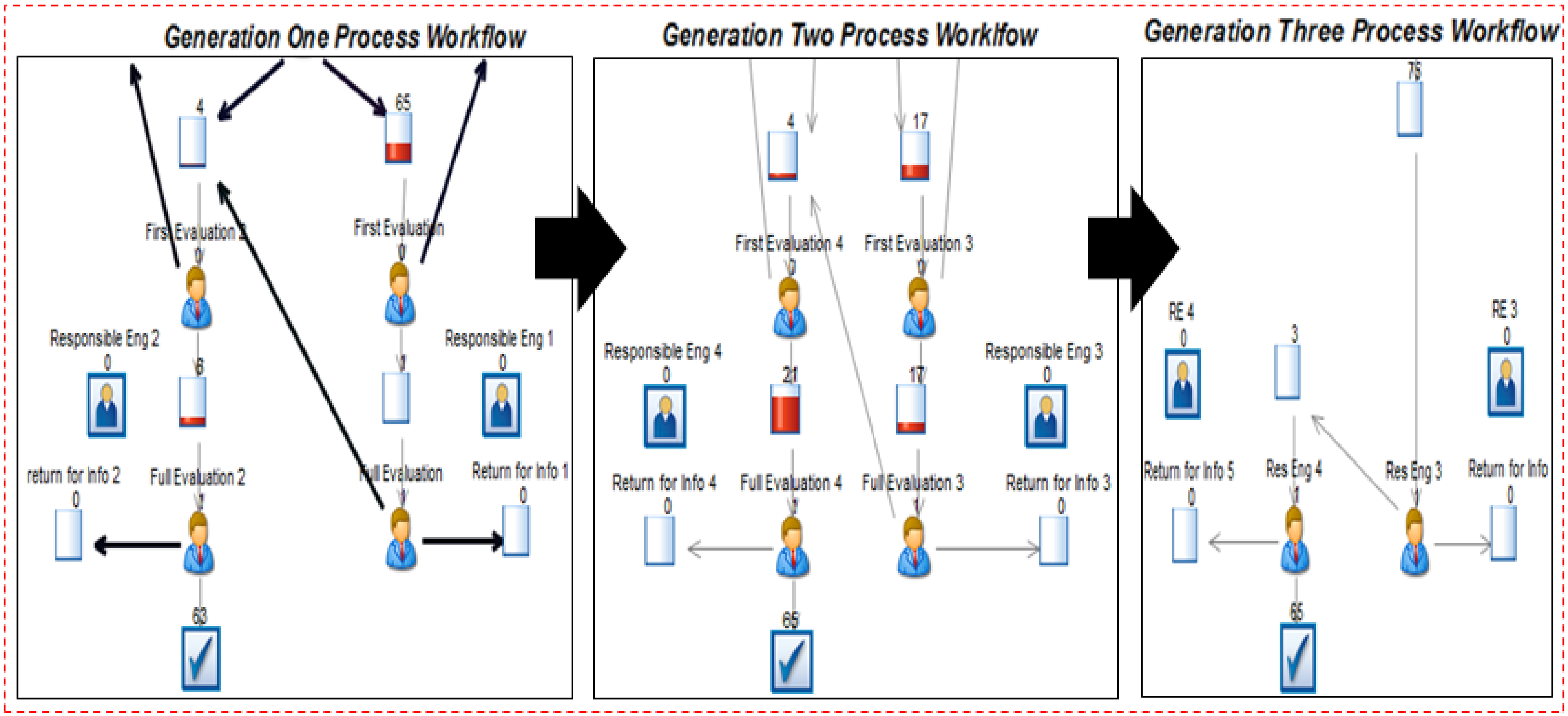
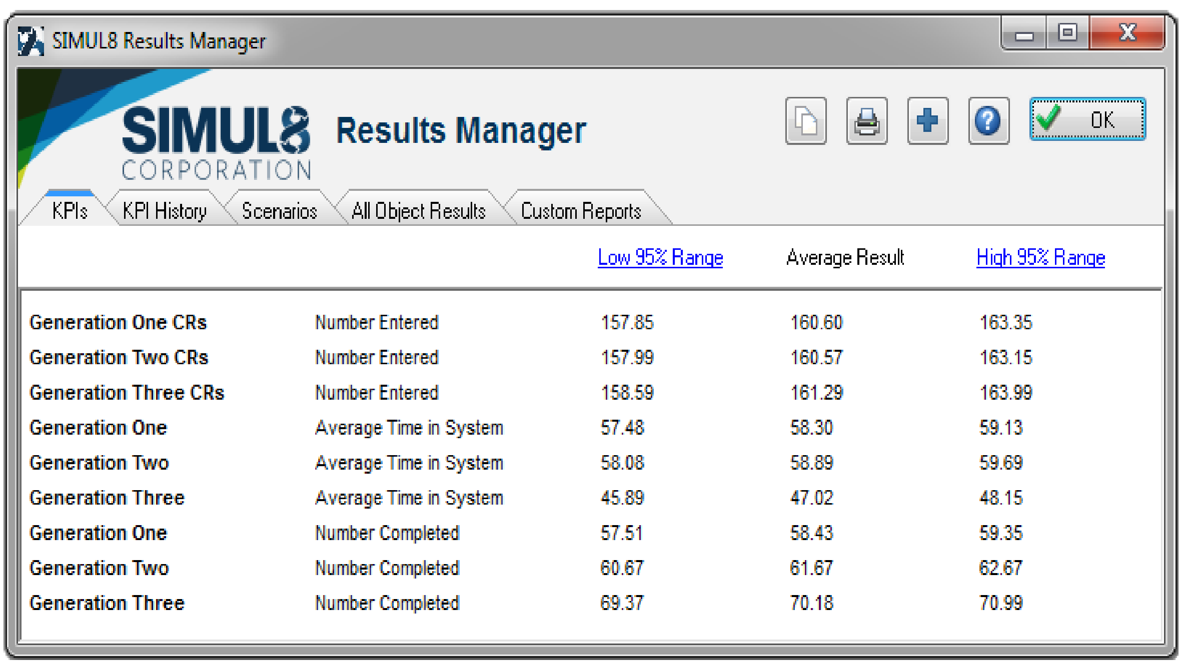


Figure 6-11: Segment (c) of the three workflows

6.2.2 Comparing the Outputs of the Three Scenarios' Simulation Models

Figure 6-12 shows the outputs of the defined KPIs. The bar charts in Figure 6-13, 6-14, and 6-15 reflect the numerical results of KPIs. As shown in Figure 6-13, the number of change requests entered in each scenario's simulation model is around 160. The reason is that the exponential distribution with the same lambda, equal to 1 per hour, is assumed for all three scenarios. Figure 6-11 illustrates the average time in the system for each scenario's simulation model. A comparison between the bar charts shows that the average time in the system, when shifting from the Generation One and Two processes to the Generation Three process, decreases by 20% ((59-47)/59). In Figure 6-15, the bar charts show that the number of completed CRs is increased by 13% ((70-62)/62). Since the average time in the Generation Three decreases, more change requests can be processed in comparison to Generation One and Two, considering the service times, and the resources for each activity centres (tasks) remain the same.



		Low 95% Range	Average Result	High 95% Range
Generation One CRs	Number Entered	157.85	160.60	163.35
Generation Two CRs	Number Entered	157.99	160.57	163.15
Generation Three CRs	Number Entered	158.59	161.29	163.99
Generation One	Average Time in System	57.48	58.30	59.13
Generation Two	Average Time in System	58.08	58.89	59.69
Generation Three	Average Time in System	45.89	47.02	48.15
Generation One	Number Completed	57.51	58.43	59.35
Generation Two	Number Completed	60.67	61.67	62.67
Generation Three	Number Completed	69.37	70.18	70.99

Figure 6-12: Results of the simulation Runs

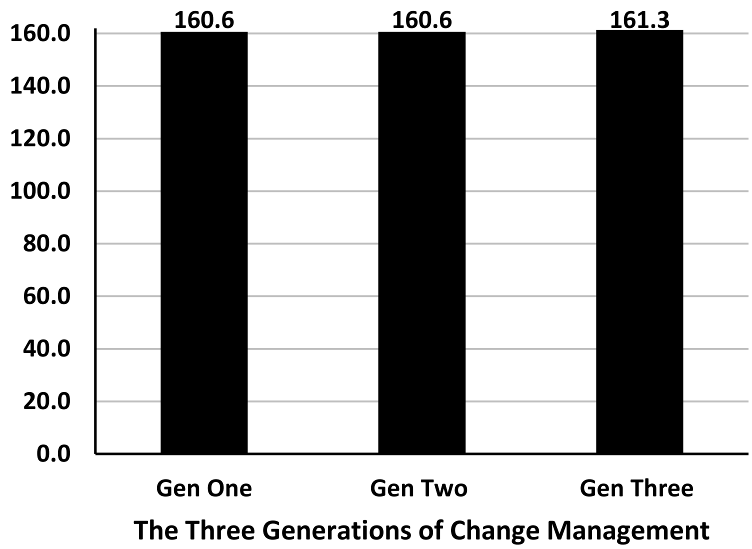


Figure 6-13: Number of CRs at the start point in each Scenario's Simulation model

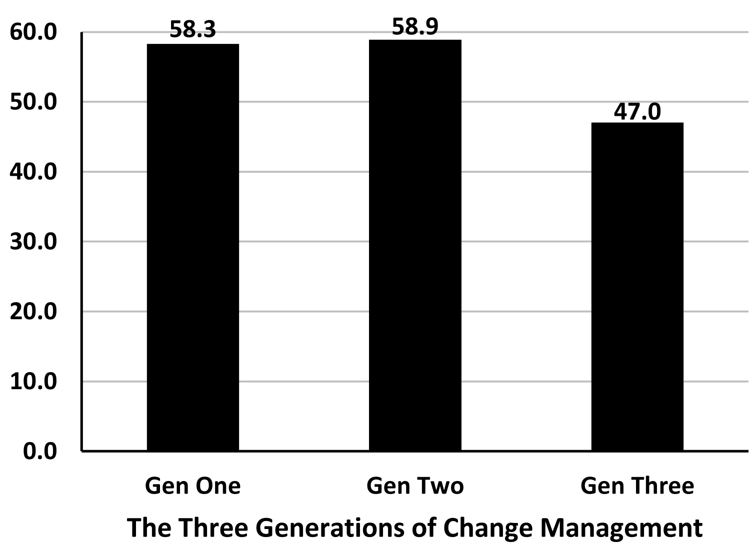


Figure 6-14: Average Time in System (hours) for each Scenario's Simulation model

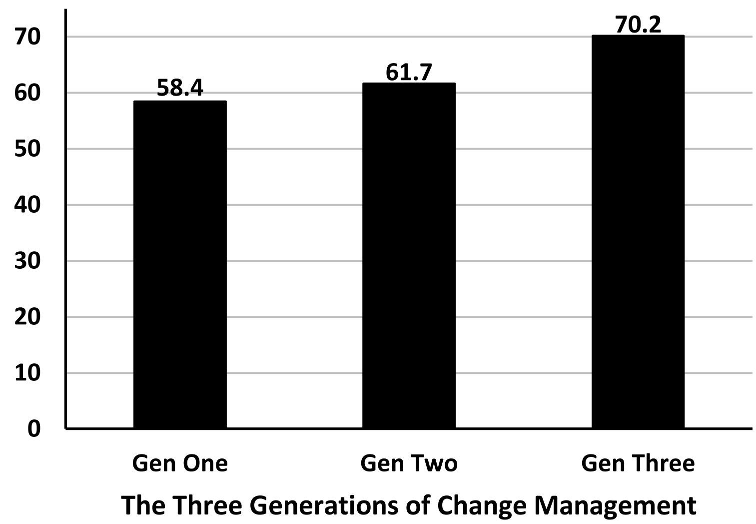


Figure 6-15: Number of CRs Completed in each Scenario's Simulation Model

The comparison between the results of the Generation One and the Generation Two processes is also interesting as the average time in the system remains the same and the difference in the rate of the number of completed CRs is not significant, only 7% ((62-58)/58). Considering these results, the author challenges the results of COMS system, mentioned by Chaorengam (2003), through which the processing time was predicted to be halved when the project shifted from the paper-based process to an electronic process. Despite the fact that Chaorengam (2003) did not consider the time of negotiations or meetings in his evaluation, the author argues these times are critical and dominant factors in the average time of a Change request evaluation in a change management process.

6.2.3 Sensitivity Analysis for the outputs

To test the outputs, sensitivity analysis was conducted. The batch size, rework rate %, and resources availability % were defined as the variables with different parameters as tabulated in Table 6-2. The simulation models for Generation One, Two, and Three were rerun for each variable and the results for the "average service time" and the "number of CRs completed" as the two simulation outputs, were selected and compared. Appendix K includes the details of the results.

Table 6-2: Variables for Sensitivity Analysis

Resource Availability %	Rework Rate %	Batch Size
10	5	1
50	15	5
100	30	15
		30

As a sample, Figures (6-16) and (6-17) illustrate the average time in the system and the number of CRs completed when the resources assigned to a task are 100% available and the rework rate is 5% but the batch size varies from 1 to 5 to 15 and then 30. As noticed, when the batch size is 1 or 5, the average time in the system and the number of CRs completed, as the outputs of the GEN 1, 2, and 3 simulation models are close together. As discussed before the batch process happens only in GEN 1and GEN 2, therefore when a batch size increases the average time in the system increases and the number of CRs completed increases and decreases respectively in both Gen 1 and Gen 2.

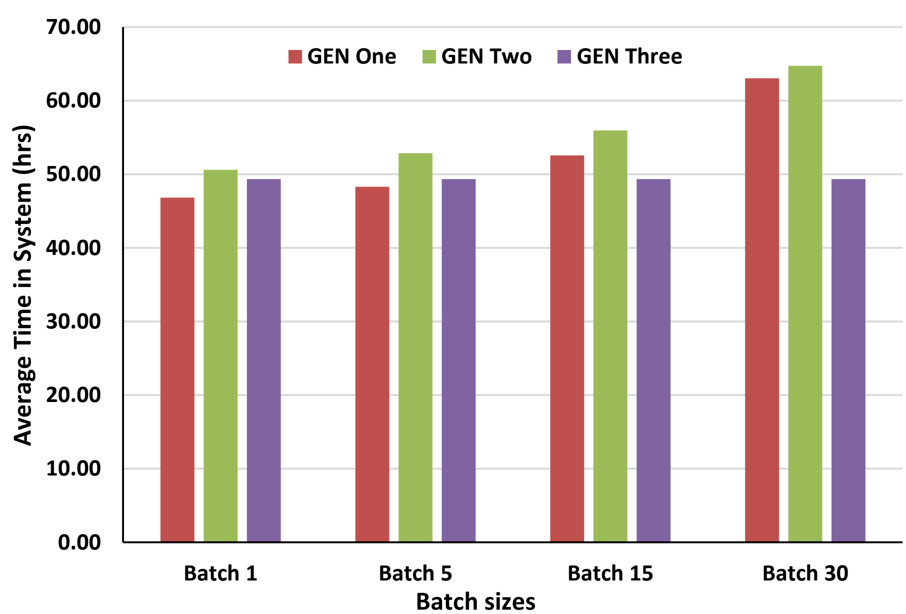


Figure 6-16: Average time in System: Batch size varies, Resource availability 100% and rework rate 5% are constant

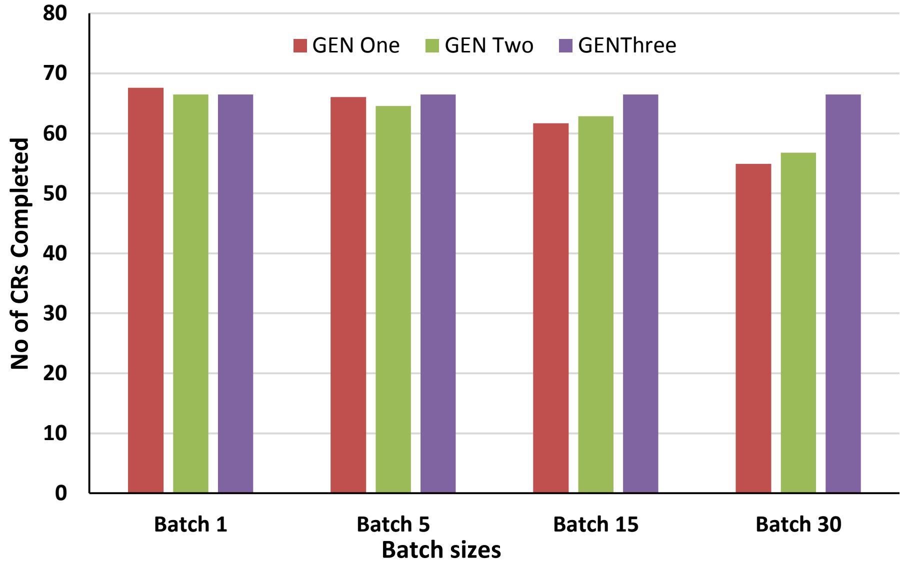


Figure 6-17: Number of CRs Completed: Batch size varies, Resource availability 100% and rework rate 5% are constant

Figures (6-18) and (6-19) illustrate the average time in the system and the number of CRs completed in Gen 1, 2, and 3 when Batch size is 30 and the resource availability is 50% for all the resources but the rework rate of the CRs in the "verify details" task varies from 5% to 15% to 30%.

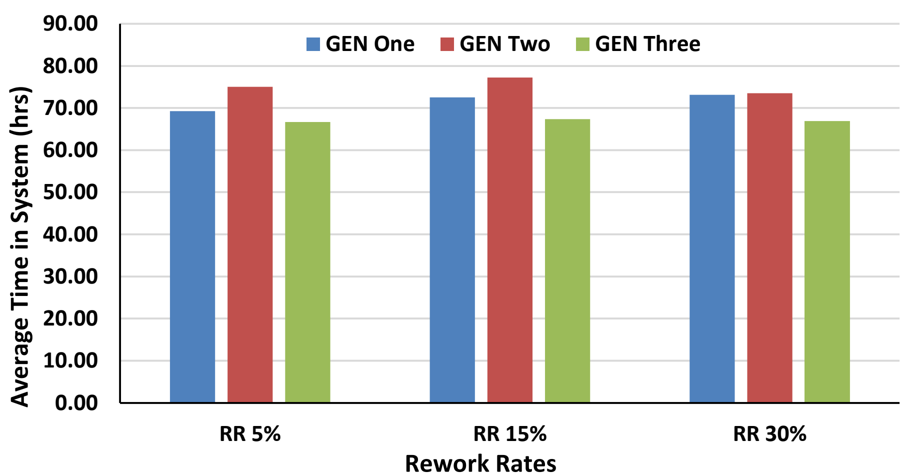


Figure 6-18: Average time in System: Rework Rate varies, Resource availability 50% and Batch size 30% are constant

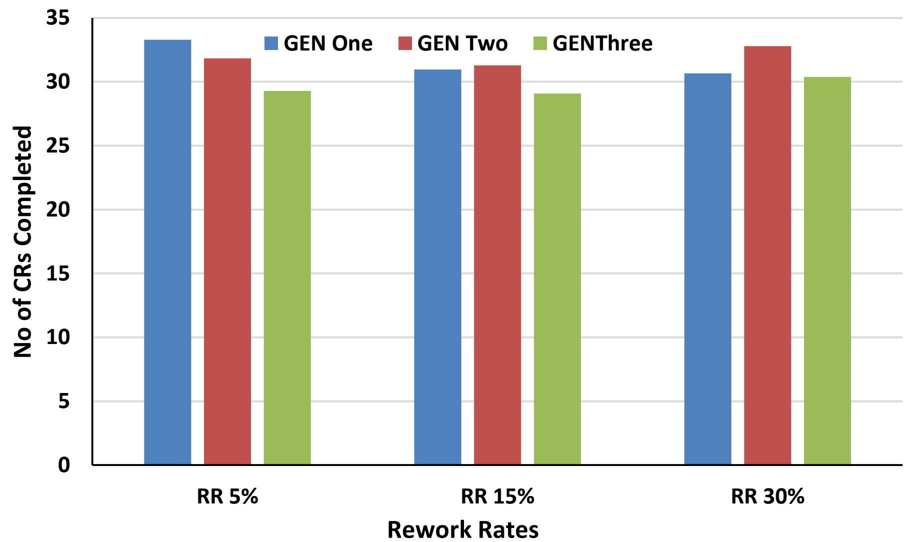


Figure 6-19: Average time in System: Rework Rate varies, Resource availability 50% and Batch size 30% are constant

When compared with Figures (6-16) and (6-17), Figures (6-18) and (6-19) also show that the rework rate does not impact on the average time of system and number of CRs completed for Gen 1 and Gen 2 and Gen 3 as do the Batch size.

6.3 Comparison between Different Workflow Implementations of Change Request

In accordance with the predefined metrics, the 8 different workflow implementations (versions), used to manage the change request automated process for the case project, were compared. Appendices (G1) to (G8) include these eight different workflow implementations. All eight different workflow implementations were first graphically compared together in order to see if the continuous improvement in the workflow implementation had been under the influence of changing the human-based tasks, machine-based tasks, adding or deleting a new human role in the process, or a combination of the aforesaid points. The results of this comparison proved that the only change was concerned with the machine-based tasks and not the human-based tasks. In other words, the human-based tasks and the roles defined in the workflow template remained intact. Figure 3-4 in Chapter 3 depicts this comparison. As confirmed with the experts, these changes improved real time notification of changes and real time traceability around the workflow instances (change requests documents) existing in the then workflow implementation. Tables 4-2 and 4-3 in Chapter 4 represent in detail the number of workflow instances (change requests) issued in each workflow implementation (version) in OGP1 and OGP2 of the case study respectively.

It should be reiterated here that the workflow implementations were not generated in sequence. This means that the completion of a preceding workflow implementation was not the inception of the succeeding one, because they were not sequentially generated. Also, it is important to know that the generation of a new workflow implementation would not cause those workflow instances initiated in the old workflow implementation to move to the new one. The arrows in Figure 6-20 represent the actual timelines of the workflow implementation in OGP1 and their overlapping times.

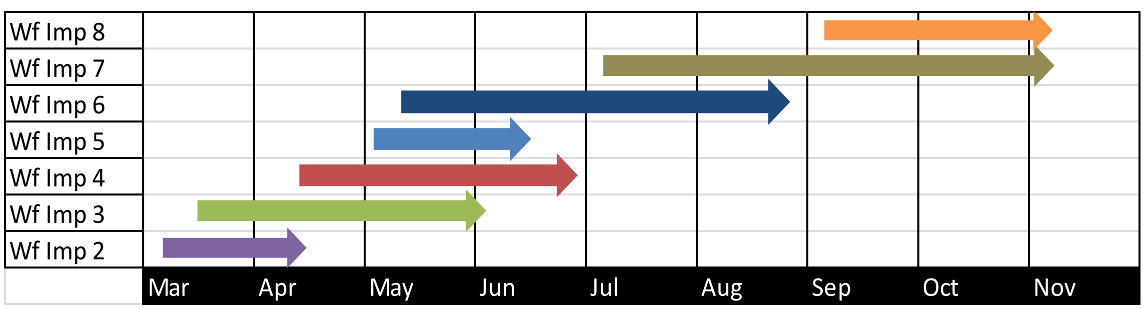


Figure 6-20: Workflow implementations' actual timelines in OGP1

Considering the above points about the characteristics of the workflow implementation, the bar charts in Figures 6-21 and 6-22 illustrate the number of workflow instances (change requests) in each workflow implementation.

6.3.1 Steady State of Workflow Implementations

Table 3-2 in Chapter 3 includes the metrics along with the methods to measure those metrics defined to meet the research objectives. One of these metrics is the steady state of the workflows in which the number of change requests (workflow instances) per workflow implementations life cycle duration is compared. Figures 6-17 and 6-18 depicts the fluctuation in the number of workflow instances when shifting from workflow implementation 1 to later workflow implementations in both OGP1 and OGP2 of the project. Following this, Table 6-2 tabulates the variation of each workflow implementation's duration in OGP1. Appendix J includes the details of calculation for workflow instances' durations in each workflow implementation. Considering the number of workflow instances fluctuation and the variation of the workflow implementation duration together, it can be concluded that the longer the workflow implementation has been in the system the more workflow instances have been evaluated, therefore the workflow implementation has a longer steady state. In other words, it demonstrates suitability and effectiveness. However, in the context of a model for continuous process improvement, it can also represent stagnation. Changing the workflow implementation has costs associated with development, learning and confusion of subsequent searches on process executions. Not changing the implementation represents opportunity cost associated with the metrics developed for the model presented in this thesis. From the analysis presented in the following subsections, it is not clear that in this particular case study that a desirable balance was achieved. However, in the general implementation of the Generation Three, it is clear that performance was improved over the Generation Two for most of the metrics. Of course this conclusion depends on two main points: first, in which particular stage of the project the workflow implementation has been executed and second, the homogeneity of the CRs generated in the workflow implementation. However, the steady state of the workflow implementations can be considered when the data of the Generation Three of change management processes from more projects are evaluated and compared. This is projected as the further research in the next Chapter of this thesis.

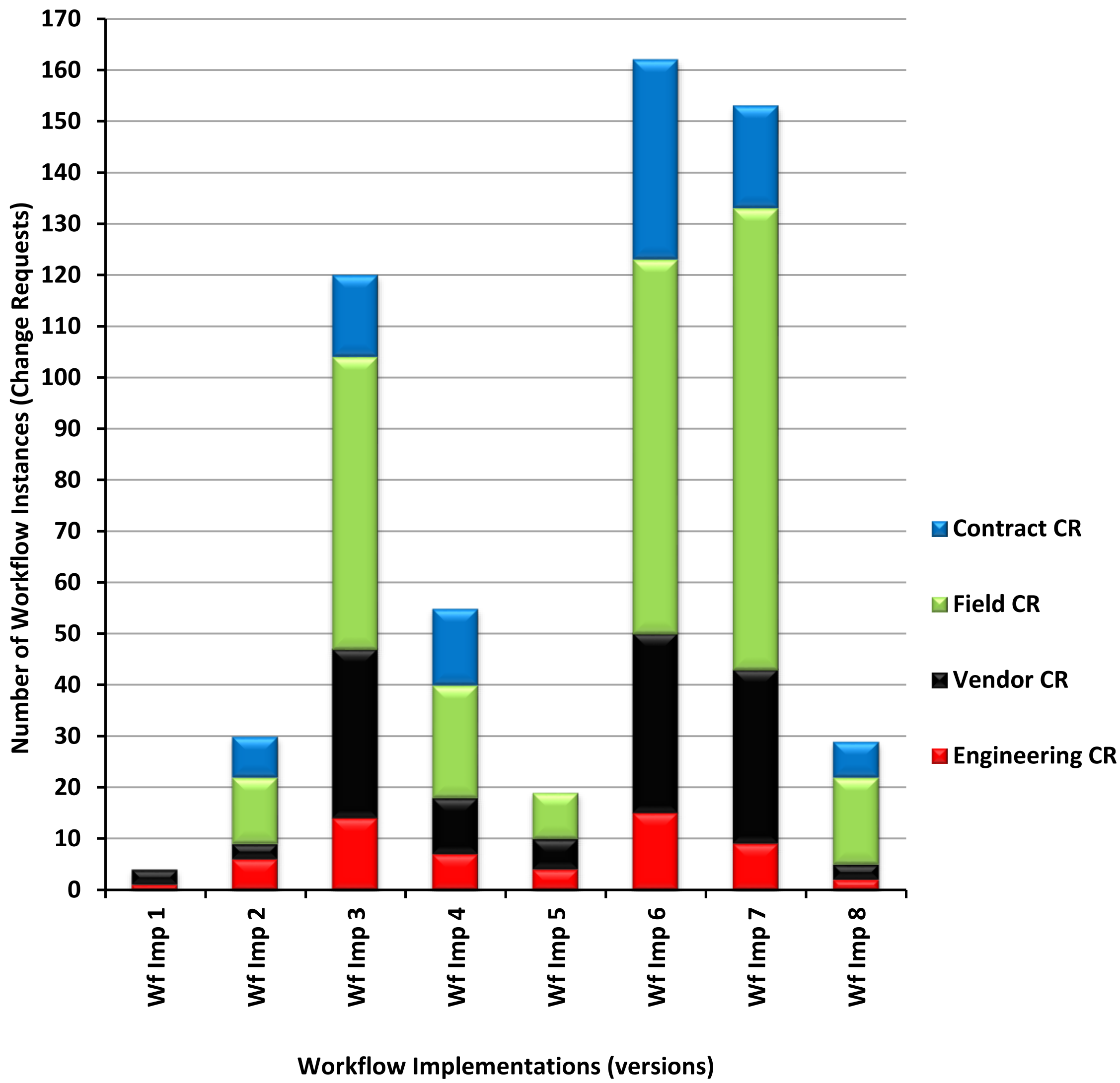


Figure 6-21: Number of workflow instances in each workflow implementation in OGP1

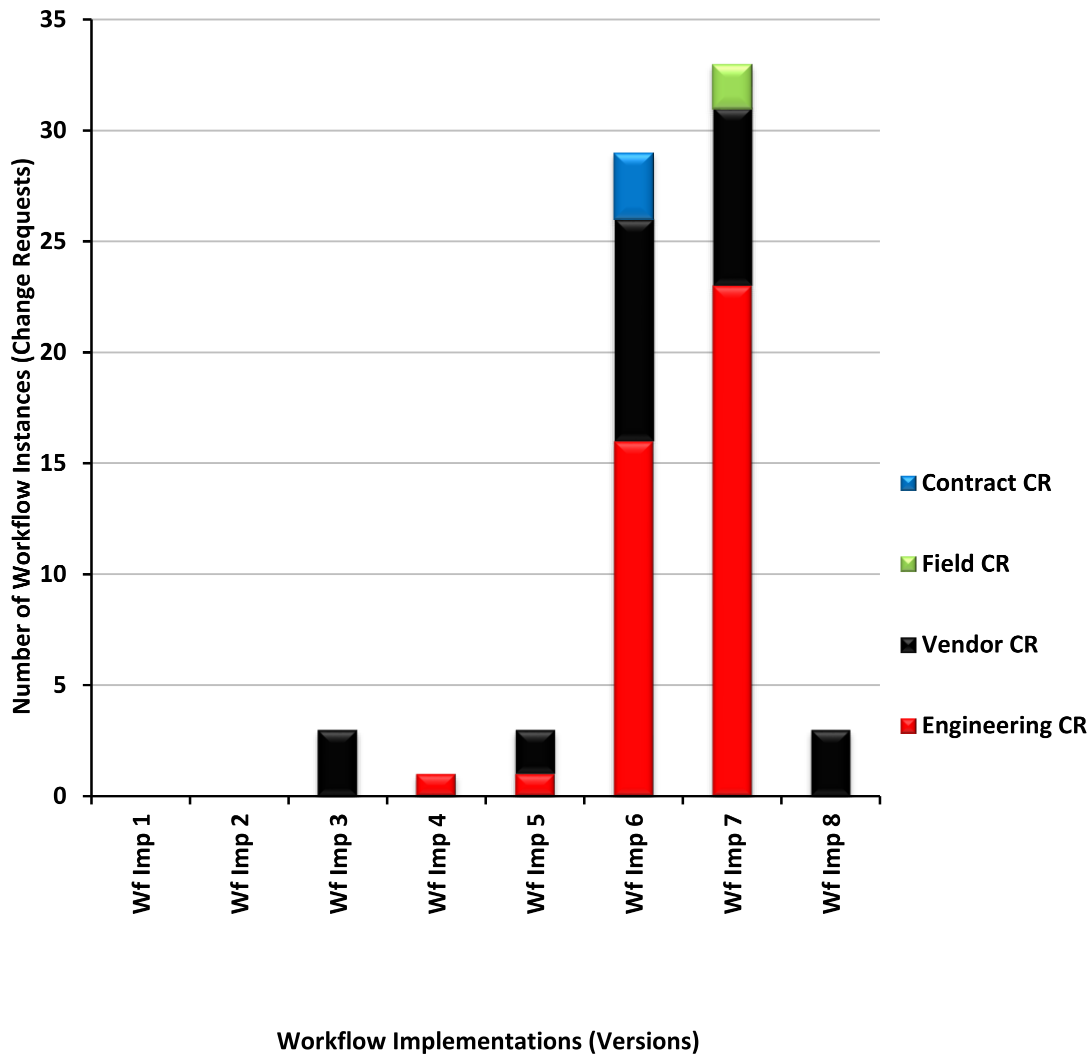


Figure 6-22: Number of Workflow instances in each workflow implementation in OGP2

Table 6-3: Workflow Implementations' nominal working hours and workflow instances' average duration

OGP1 Workflow Implementation	Start Date of Workflow Implementation	Finish Date of Workflow Implementation	Workflow Implementation Duration Working Hours (Working Days)	Workflow Instance Average Duration	No of workflow Instances	Incomplete or Outlier Workflows	No of complete Workflows	Average Duration of each Workflow Instances
1								
2	Mar 05, 2011	Apr 14, 2011	348 (29)	150:33:58	30	2	28	5:22:39
3	Mar 14, 2011	Jun 03, 2011	720 (60)	118:09:38	120	17	103	1:08:50
4	Apr 15, 2011	Jun 28, 2011	636 (53)	135:57:41	55	5	50	2:43:09
5	May 03, 2011	Jun 13, 2011	360 (30)	156:55:59	19	2	17	9:13:53
6	May 10, 2011	Aug 22, 2011	900 (75)	160:24:41	162	11	151	1:03:44
7	Jul 08, 2011	Nov 07, 2011	1044 (87)	158:30:10	153	17	136	1:09:56
8	Sep 07, 2011	Nov 07, 2011	528 (44)	205:18:40	29	2	27	7:36:15
Ave (hrs.)				155:07:15				
Ave (wk.)				2.59				

To test the steady state in another automated process, like the Generation Three change management process, the RFI's automated process (request for information) was also analyzed based on the data of the RFI documents and 9 RFI workflow implementations. This analysis revealed that almost the same pattern of steady state while moving from the RFI's preliminary workflow implementations to the next ones (Figure 6-23)

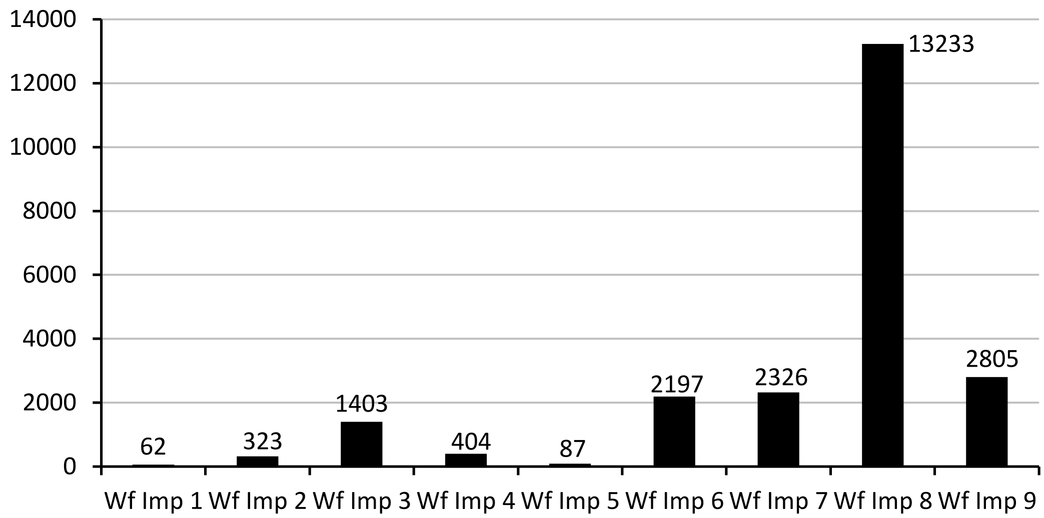


Figure 6-23: Number of RFI workflow instances in RFI workflow implementations

6.3.2 Workflow Instances' Average Duration Reduction in Each Workflow Implementation

Improvement in workflow instance's average duration was another metric which was considered in the continuous improvement of the workflow implementations. The nominal working time (in hours) of each workflow implementation is shown in Table 6-2. The calculation of the nominal working time, based on 12 working hours per day in 5 working days, is the difference between the smallest and the largest dates and times recorded in the database. The smallest date and time is concerned with the first CR initiated in a particular workflow implementation but the largest one is not necessarily related to the last CR workflow instance because, as explained in Chapter 4 the behavior of the CR is *not* First In First Out. Thus, a CR may outstay its succeeding one.

Figure 6-24 illustrates the workflow implementations' average nominal working times which fluctuates from one workflow implementation to another. Two points are worth noting: first, as mentioned before, the CRs issued in each workflow implementation are not homogeneous. That is, some CRs, due to their higher dollar amount, may require deeper evaluation in terms of cost and schedule impact and more negotiations than other CRs. During which workflow implementation these types of CRs have been initiated significantly affects the average duration of that workflow implementation. Second, the issuance rate of CRs in each workflow implementations varies. For example, depending on the phase of the project, more CRs have been initiated in June when workflow implementation 6 has been in execution compared to October when workflow implementation 8 has been active. As mentioned before, the availability of the staff has the paramount importance when it comes to evaluating the CRs.

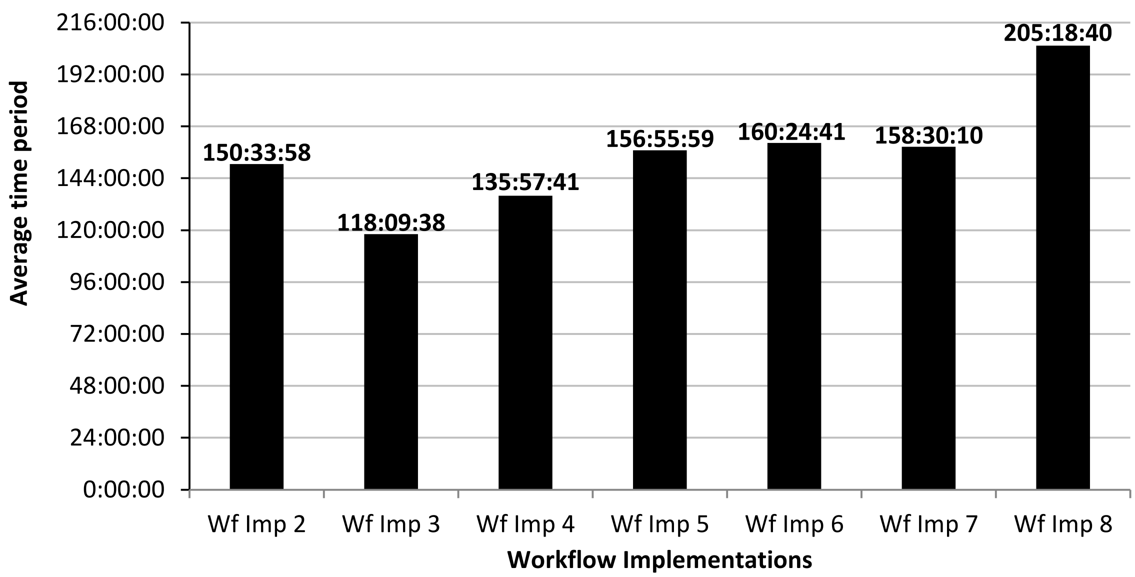


Figure 6-24: Average duration of workflow instances in each workflow implementation

The aforesaid points are compatible with what experts involved in OGP1 and OGP2 mentioned while being interviewed. They acknowledged that *despite the fact that they would expect significant time saving due to the implementation of the change request automated process and continuous improvement in the project, the main advantages proved to be better traceability of the CRs and compliance in the change management process, not the time savings*. As discussed before, as long as it is assumed that the CRs are homogeneous, the issuance rate of CRs is the same, and the staff availability remains the same, the automated process can save time from 5% to 20% of the change management time period. The homogeneity of the CRs and its effect on the time length of the workflow implementations can provide an opportunity for further research on this era. This point is discussed in the future research Section of Chapter 7.

6.3.3 Compliance

By definition, compliance is the conformity in fulfilling official requirements defined to meet an objective set. Compliance is also the structure of the workflow implementation and the workflow engine that enforces “conformity” with company’s policy and legal regulations. This and the time limit are also related to enforcing “compliance” with contract terms on minimum response times and due diligence. Compliance, as another metric under consideration, was measured by considering the “tasks with respond by date” in the Generation Three change management process. In the database there was a “Response By” column with the due dates assigned to these activities (table 3-1 database table in Chapter 3). If a project team member, for instance a review participant, would not review a CR in the “Review Participant” task by the due date, the workflow engine would send a *warning* to that person to remind them about the task to be done on the CR (reviewing the CR). In the change request workflow there were seven activities with warning as follows:

- Review Participants
- Review (Engineer)
- Approve (Engineer)
- Approver
- Approve (Manager)
- Approve (Site Construction Manager)
- Approve (Assistant Site Construction Manager)

As shown in the following formula, a *delay time* is the difference between the due date taken from "Response By" column and the date from "Completed date time" column.

$$Delay\ time = Response\ by\ date - Complete\ date\ time$$

As shown in Figure 6-25, the delay time means that the project team member has responded to the CR *after* the due date allotted in the "response by" column.

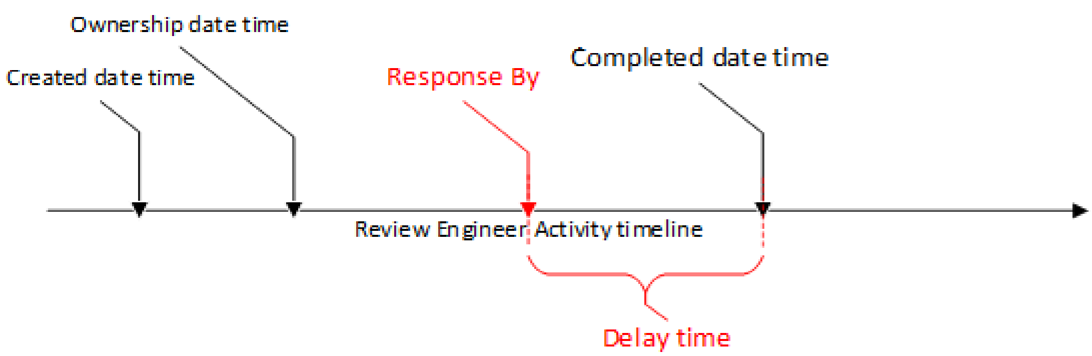


Figure 6-25: Delay Time in the tasks with "Response By" Date

Obviously if the project team member has completed the activity *before* the due date (completed date time < response by date) then the project team member has abided by the due date and can be construed as their compliance to the process.

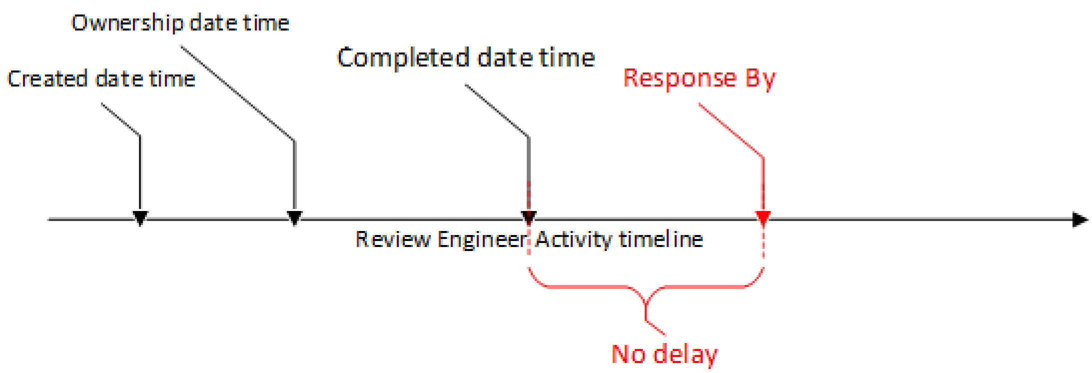


Figure 6-26: No Delay in the tasks with "Response By" Date

Considering the above concept about compliance, the number of delayed CRs and the average delay time for each of the aforesaid tasks in each workflow implementation were calculated (Figure 6-27 and Figure 6-28). Figure 6-27 and Figure 6-28 respectively illustrate the number of delayed CRs and the average delay time (based on working hours) of the delayed CRs in the tasks with "response by" date for each workflow implementation. For instance, in Figure 6-27 the number of delayed CRs in workflow implementations 2 and 3 for the "review participants" task are 56 and 76 respectively. In Figure 6-28, the average delay time for these CRs in the same workflow implementations for the same task is 147.9 working hours and 129.77 working hours. This shows that for the "review participants" task, although more CRs are delayed in workflow implementation 3 than workflow implementation 2, its average delay time is less than that in workflow implementation 2. This pattern can be observed in other tasks as shown in Figure 6-27 and Figure 6-28. The data on these Figures is also tabulated in Table 6-4 and Table 6-5. Further, the data analysis proved that there was no delay time in later workflow implementations (the bar charts of the workflow implementations 4, 5, 6, 7, and 8 are zero as shown in Figures 6-27 and 6-28). Hence it can be argued that in the Generation Three process workflow compliance was improved as later workflow implementations have been developed. It can also be argued that initial bugs were ironed out after three implementations by focusing on important performance metrics as drivers of continuous improvement.

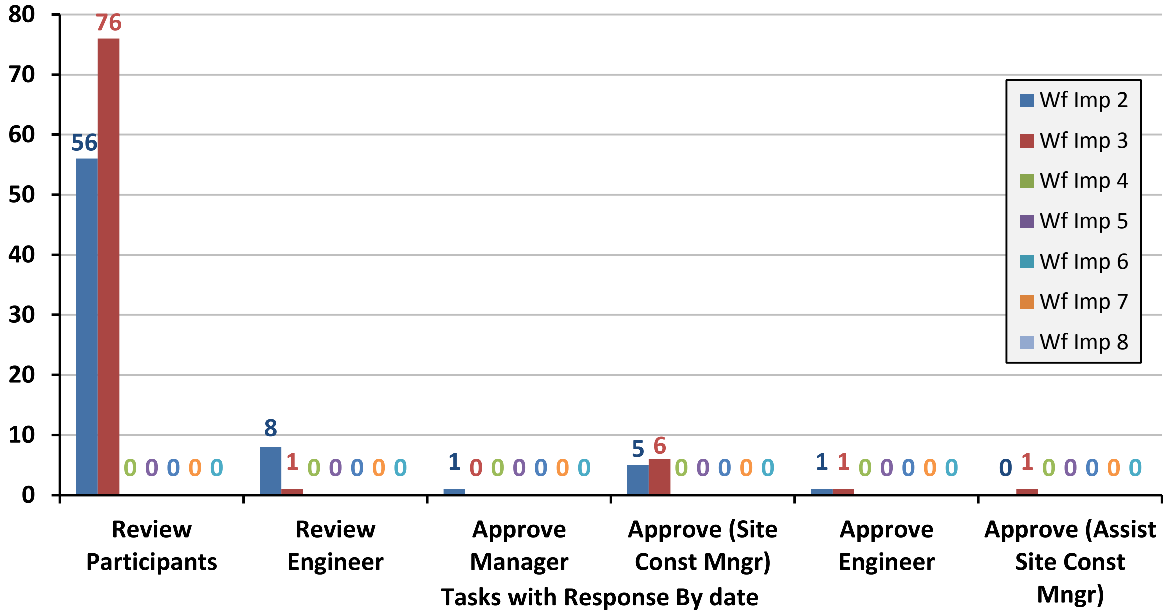


Figure 6-27: Number of delayed CRs in the tasks with "Response By" date for 1 to 8 workflow implementations

Table 6-4: Number of delayed CRs in the tasks with "Response By" date for 1 to 8 workflow implementations (tabulated format)

Tasks with "Respond By" dates	Workflow Implementations						
	2	**3**	4	5	6	7	8
Review Participants	**56**	**76**	0	0	0	0	0
Review Engineer	**8**	**1**	0	0	0	0	0
Approve Manager	**1**	**0**	0	0	0	0	0
Approve (Site Const. Mngr)	**5**	**6**	0	0	0	0	0
Approve Engineer	**1**	**1**	0	0	0	0	0
Approve (Assist Site Const. Mngr)	**0**	**1**	0	0	0	0	0

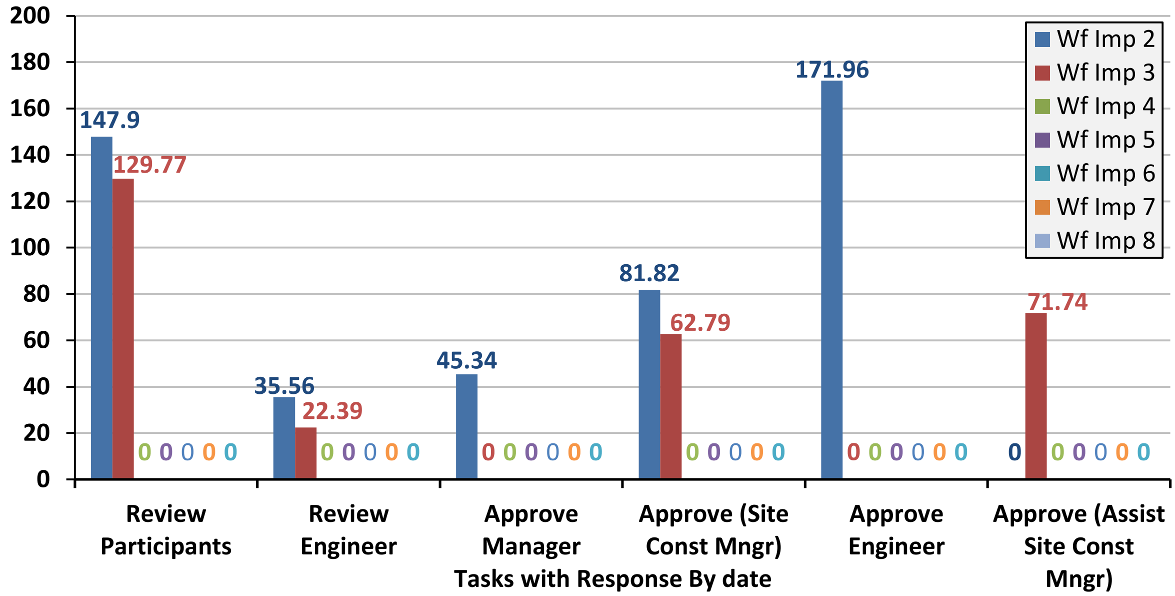


Figure 6-28: the average delay time of CRs in each task with "Respond By' date for 1 to 8 workflow implementations

Table 6-5: the average delay time of CRs in each task with "Respond By' date for 1 to 8 workflow implementations (tabulated format)

Tasks with "Respond By" dates	Workflow Implementations						
	2	**3**	4	5	6	7	8
Review Participants	**147.9**	**129.77**	0	0	0	0	0
Review Engineer	**35.56**	**22.39**	0	0	0	0	0
Approve Manager	**45.34**	**0.00**	0	0	0	0	0
Approve (Site Const. Mngr)	**81.82**	**62.79**	0	0	0	0	0
Approve Engineer	**171.96**	**0.08**	0	0	0	0	0
Approve (Assist Site Const. Mngr)	**0.00**	**71.74**	0	0	0	0	0

6.3.4 Traceability

Traceability pertains to the historical records of any change request which has entered into a workflow implementation or in other words the details of any workflow instance's execution in a workflow implementation. The historical records can illustrate the date and the time when a change request has arrived at or left a task (work centre), who has worked on that particular change request in that task (work centre), and the then status of the change request. Appendices A and B respectively illustrate a snapshot of the database of the Generation Three Process Workflow for a Canadian oil and gas megaproject (the research case study) and the old change logs (a spreadsheet) of the old process being followed prior to implementing the Generation Three in the aforesaid project.

For instance, in the old change log, the initiation date and approved date of the change request ECO-051 is manually stamped as 17/May/2010 and 11/Jun/2010 respectively. What is not *traceable* is to whom, to what task, and when this change request has been delivered between these two dates. In addition, manual updates are prone to human mistakes as a typo example, the unique code of the change request ECO-052 is recorded as EC0-052.

As opposed to what was explained about the *untraceability* in the change log (appendix B), the document management system automatically records all the detailed data of a change request in the database with no human mistake. The data can be extracted by Structured Query Language (SQL), a special-purpose programming language, in customized tables from database management system (DBMS). Appendix A is a customized table with all extracted data about the change requests required for this thesis. As seen, an automated workflow-based process, like the Generation Three results in better traceability of the change requests generated in a workflow implementation.

6.4 Summary

To meet the first objective of this research, this Chapter compared three simplified simulation models developed based on the three scenarios respectively considered for the three Generations of change request processes. The results of this comparison showed that in a homogenous environment (where the same process of the change request in the three levels (Generation One, Generation Two, and Generation Three), the homogeneity of the change requests types, and the same arrival rate of the change requests exist), the automated process can improve the duration of the change request evaluation. The main reason of this improvement pertains to the elimination or minimization the batch sizes in the Generation Three and to some extent the elimination of change request redelivery, or rework due to human mistakes. The change request's electronic circulation that takes over physical change request distribution amongst the tasks has minimum impact on this improvement in a change request process. Returning of change requests for further information or clarification may create another type of rework. However, this "return for information" is not eliminated in the Generation Three, because unlike the change request redelivery, it relies on the project team members' knowledge that should be gained through negotiations and meetings. To meet the second objective, 8 different workflow implementations of the case study (a Canadian oil and gas megaproject) were compared together according to the defined metrics: steady state, workflow's average duration (time), and compliance. The results of comparing workflow implementations, for workflow's steady state defined as the proportion of the number of CRs in a workflow implementation over the duration of that workflow implementation showed that this proportion is greater in later implementations than that in the earlier ones. This means that the later implementations have longer steady state than the earlier one. The results indicated that the later workflow implementations, as the improved versions of the earlier ones, did not necessarily reduce the duration of the workflow instances generated in the later workflow implementations. The results indicated that the compliance has improved in later implementations of the workflow, since the delay time has been decreased in the activities with the response by due date. The manual change logs in Generation One and Two processes, used to record the details of a change request are prone to human mistake which leads to difficulty in the traceability of the historical data of a change request, upon request. However, this issue is rectified in the Generation Three automated process due to the automated recordability of the database management system of all historical records from the initiation to the completion of any change request.

Chapter 7
Summary, Conclusions, and Further Research

7.1 Summary of the thesis

The occurrence of changes in construction megaprojects has made project stakeholders, especially project owners, think of the implementation of novel approaches for the circulation of high volumes of change documents. Due to the dominance of the “fast track” approach, for some years the industrial megaproject sector has utilized advanced change management, which is based on formal process-based approaches using increasingly advanced Information Technology (IT). Despite this fact, much of the construction industry still relies on change management systems with loose and blurred processes. The dependency of these processes on the human discipline, especially for the repetitive human-based tasks such as hardcopy documentation of physical change files circulations, is the main cause of mistakes that result in rework, which in turn leads to delay, cost overrun and litigations in managing of changes.

As the proposition of this research, a change management system with an automated workflow-based process is required. This system is a part of an EPPMS (electronic product and process management system), a tool supporting execution of megaprojects. The elimination or change of repetitive human-based tasks to machine-based tasks in the automated process leads to reducing the rate of rework and improving compliance, resulting in the reduction of duration of change documents’ evaluation.

In line with the proposition of this research two main objectives were defined as follows:

- Evaluate and quantify the difference between levels of automation of change management processes

- Develop and validate a model for continuous improvement of automated change management processes as per defined metrics.

Current change management systems were divided into two levels. The Generation One of change management was defined as the first level in which change documents are physically archived and circulated amongst the project team members through faxes or snail-mails as the means of communication and document circulation. The Generation Two of change management was defined as the second level in which scanned (PDF) change documents are circulated amongst the project team members through the Internet, computers, and personal emails.

To fulfil the first objective of this research, these two processes were compared with the Generation Three change management, a proposed model the foundation of which is workflows, formal process, workflow engine, Document Management System, Database Management System, and cloud-based computing. To quantify the aforesaid levels and compare them, a megaproject in which these levels were used was ideal. Therefore, a Canadian oil and gas megaproject was selected as the case study in which three levels of change management processes were utilized. Access to this project was facilitated by Coreworx™, the research partner and by the owner of the megaproject.

The document analysis, database analysis, and interviews with project experts of the case study provided an accurate comparison between the Generation Three and a mixed Generation One and Two, as the two processes used for managing the change requests initiated in the procurement and construction phase of the megaproject. This comparison revealed that the project roles or the project team members and the sequence of the activities in the change request process remained intact. This fact considered, shifting from the Generation One and the Generation Two processes to the Generation Three process in the project showed that the duration of change request workflow process may be reduced.

In the change request process, two types of document loop were observed; (a) change request redelivery and (b) return for information. In (a), the change request is sent back to the sender due to change request delivery to wrong person, missing attachment or incomplete Section of the form such as no document ID or sender's signature. These were the common mistakes identified in a spreadsheet used as a change log for the mixed Generation One-and-Two process in the case study. These mistakes, however, were minimized if not totally eliminated in the Generation Three due to the existence of the workflow engine, database management system, and document management system making these tasks automated throughout the process.

In the return-for-information loop, the change request is sent back to clarify ambiguity which in turn requires human judgment. The essential of human judgment is tacit knowledge accumulated by a person's experience and can be gained and shared through meetings and negotiations to make the right decision about the change request retuned for information.

The reduction of the duration of the change documents' evaluation depended on the capturability of the workflow behavior and the homogeneity of the change requests; vendor, engineering, field, and contracts. The capturability of the workflow behavior was defined as capturable data and uncapturable data. The former included three types of time stamps named as "Created date time", "ownership date time", and "completion date time" indicating receiving, opening and evaluating, closing and sending a change request from one activity (task) to another in the automated process. These time stamps were registered in the database of the automated process or manually entered in the change log. The latter, uncapturable data was related to the time of phone calls, negotiations, or meetings spent in line with the evaluation of change requests. This data was never registered in the database of the automated process. Nor was it, as a form of comments, found in the change logs.

The homogeneity of the four aforesaid types of change requests proved challenging since neither in the database of the Generation Three process nor in the change logs was the discrepancy of change requests leading to different time evaluation of the change requests registered. For instance, it was not clear how different (or similar) the engineering change request "A" evaluated in the process for 180 working hours is from the engineering change request "B" evaluated in the automated process for 65 working hours. To better show the challenges mentioned above, the behavior of the change request workflow was compared to a simple production line of a factory floor where the products were homogeneous and capturability of the time was clearer, therefore, such a simulation model could lead the managers towards the improvement of the production line.

To compare the levels of change request processes, it was assumed that the change requests in the three processes were homogeneous and each human-based task would follow the same sort of time distribution defined to each task in the simulation model. With these two main assumptions considered, the results of this comparison revealed that the percent time reduction in both the Generation One and the Generation Two processes remained the same while it was improved by about %20 in the Generation Three process. In this particular case, the rate of rework was 5% and the batch size delivered in Gen1 and Gen2 processes was 20 CRs. To see the impact of batch size, rework rate, resource availability, defined as the variables, on the service time in the system and number of CRs completed, sensitivity analysis was conducted. The results revealed that shifting from Gen1 and Gen2 to Gen3, the batch size has more impact the simulation outputs while rework rate and resource availability.

As for the continuous improvement process program (CIPP) for the Generation Three of change management process, the different workflow implementations used in the project were considered. The workflow implementation was defined as any change made, with the aim of improvement, to the workflow template which was defined as the basic structure of the workflow.

Considering this definition, a new workflow implementation would be an improved format or version of its preceding one. Workflow instances were associated with each execution of the workflow triggered by the initiation of a change in the workflow. Considering the CIPP cycle, a comparison was made between the workflow implementations based on average duration of workflow implementations, compliance, and steady-state as the defined metrics.

Due to the different number of workflow instances and variable time period of each workflow implementation, the results for the average duration revealed fluctuation in the average time of the workflow implementations. In other words, improving from an old workflow implementation to a new one did not necessarily lead to average-time improvement or the reduction of the average duration of the workflow instances existing in the new workflow implementation compared to those in the old one. This result was in line with the comments made by the experts of the project during the interview, since it was acknowledged that *as opposed to the first assumption of the project stakeholders that the implementation of the automated workflow may improve the average duration of the change request's* <u>*evaluation period*</u>*, there proved to be no significant time savings when the change management process was switched from the Generation One and Generation Two processes to the Generation Three process*. The experts, however, acknowledged that *due to the use of automated workflows, traceability and compliance of the change requests during their evaluation process was significantly improved.*

As for the workflow user's compliance, the comparison of the workflow implementations revealed that the project team members, as the workflow users, abided by the due dates set to the activities for which they were responsible. Remember that the workflow engine sends automated reminders. Therefore, the delay time which was the time difference between the due date and completion date of the change requests was reduced in later workflow implementations.

The steady state was associated with the proportion of number of CRs in a workflow implementation over the execution period of the same workflow implementation. The results of the data analysis of 8 workflow implementations showed that the steady state and effectiveness in later workflow implementations is greater than those in the earlier workflow implementations.

7.2 Conclusions and Research Contributions

The preceding investigation, mechanistic arguments, and the results of the validated simulation model of change management which was executed for the three identified generations led to the conclusions that the "Generation Three" approach when executed in megaprojects similar to the case study in this research should result in:

a. better traceability of change documents throughout the automated workflow-based process due to the recordibility of date, time, and current status of the change documents in each task,

b. better process compliance due to the elimination of rework in repetitive tasks prompted by the automated workflow engine,

c. reduction of the duration of the change management workflow considering the limitations of IT for reducing the duration of professional work.

This research has thus led to a better understanding of the potential of automated management systems for improving processes such as change management in terms of traceability, compliance, and duration, but also of the limitations of such systems such as their ineffectiveness in substantially expediting professional practices that require off-line analysis, communication, negotiation and judgment.

7.3 Further Research

The uncapturable data was the main issue in the accuracy of the three levels of change management process comparison. This comparison can be reconsidered should such data be captured in a similar project.

In order to capture the uncapturable time or the time spent out of the system of an automated change management process, ideally in an on-going megaproject where an automated change management process is being used, the project team members can be provided with a questionnaire in which they may record the time they have spent out of the system for the change requests in the evaluation process. This data then can be used in the change request simulation model to get more accurate results.

The fluctuation in the time and the number of workflow instances revealed how steady the workflow's state could be when moving from the earlier workflow implementations to the later ones. This conclusion is based on the case study results. Therefore, similar projects in which automated change management processes with various workflow implementations have been deployed should be observed. This may lead to a better comprehension of the behavior of the workflows as per the metrics defined. It may also result to define two extremes within which the steady state of workflow implementation may fall.

Like change management, contingency management is a process. An automated sub-process for contingency management under the Generation Three of the change management automated workflow-based process is another means by which a more effective control of budget and cost could be achieved. This development should be pursued.

This research's focus was on one particular project with 8 change request workflow implementations indicating the evolutionary process from one workflow template. The availability of sufficient data on different change request workflow templates and workflow implementations from several megaprojects can lay the foundation to design a perfect change request workflow.

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Appendix A: A snapshot of the case study database

Change Type	WF_ID	Doc_id	Activity display name	Created date time	Ownership Date Time	Completed date time	Response By	Name	Current Status	Version
ECR	26	Confidential	Change Request Draft	3/3/11 0:34	3/3/11 0:38	3/10/11 1:31	NULL	Confidential	Submit	1
ECR	26	Confidential	Verify Details	3/10/11 1:31	3/10/11 14:14	3/10/11 14:15	NULL	Confidential	Send On	1
ECR	26	Confidential	Change Request Participants Verification	3/10/11 14:15	3/10/11 14:21	3/10/11 14:58	NULL	Confidential	Send On	1
ECR	26	Confidential	Review (Engineer)	3/10/11 14:58	3/10/11 15:11	3/10/11 15:12	3/16/11 23:00	Confidential	Send for Approval	1
ECR	26	Confidential	Approve (Approver)	3/10/11 15:12	3/10/11 15:12	3/10/11 15:13	3/21/11 23:00	Confidential	Approve	1
ECR	26	Confidential	Approved Close Out	3/10/11 15:13	3/10/11 15:17	3/10/11 15:27	NULL	Confidential	Send On	1
VCR	27	Confidential	Change Request Draft	3/3/11 16:44	3/3/11 16:45	3/3/11 19:48	NULL	Confidential	Submit	1
VCR	42	Confidential	Approver (Manager)	3/10/11 15:23	3/11/11 17:20	3/11/11 17:21	3/23/11 23:00	Confidential	Return for Information	2
VCR	42	Confidential	Review (Engineer)	3/11/11 17:22	3/11/11 17:49	3/11/11 18:06	3/13/11 23:00	Confidential	Send for Review	2
VCR	42	Confidential	Change Request Participants Verification	3/11/11 18:06	3/11/11 18:07	3/11/11 18:08	NULL	Confidential	Send On	2
VCR	42	Confidential	Review (Participants)	3/11/11 18:08	3/14/11 13:18	3/14/11 13:21	3/14/11 23:00	Confidential	Send On	2
VCR	42	Confidential	Review (Participants)	3/11/11 18:08	3/15/11 13:38	3/15/11 13:53	3/14/11 23:00	Confidential	Send On	2
VCR	42	Confidential	Review (Participants)	3/11/11 18:08	3/11/11 21:24	3/11/11 21:25	3/14/11 23:00	Confidential	Send On	2
VCR	42	Confidential	Review (Participants)	3/11/11 18:08	3/22/11 23:37	3/22/11 23:42	3/14/11 23:00	Confidential	Send On	2
VCR	42	Confidential	Review (Participants)	3/11/11 18:08	3/14/11 12:27	3/14/11 12:28	3/14/11 23:00	Confidential	Send On	2
FCR	141	Confidential	Approve (Engineer)	4/1/11 17:22	4/4/11 13:57	4/4/11 13:57	4/5/11 17:00	Confidential	Send for Approval	3
FCR	141	Confidential	Approved Close Out	4/4/11 13:58	4/4/11 15:08	4/4/11 15:09	NULL	Confidential	Send On	3
FCR	142	Confidential	Verify Details	3/18/11 16:43	3/18/11 16:52	3/18/11 16:53	NULL	Confidential	Send On	3
FCR	142	Confidential	Change Request Participants Verification	3/18/11 16:54	3/18/11 16:55	3/18/11 16:56	NULL	Confidential	Send On	3
FCR	142	Confidential	Approve (Site Construction Manager)	3/18/11 16:56	3/18/11 22:18	3/18/11 22:18	NULL	Confidential	Approve	3
FCR	142	Confidential	Approve (Site Construction Manager)	3/18/11 16:56	3/18/11 22:18	3/18/11 22:18	NULL	Confidential	Approve	3
FCR	142	Confidential	Approve (Assistant Construction Manager)	3/18/11 22:18	3/21/11 15:34	3/21/11 15:35	3/28/11 23:00	Confidential	Approve	3
VCR	362	Confidential	Approve (Engineer)	5/20/11 21:01	5/24/11 13:49	5/24/11 14:12	NULL	Confidential	Send for Approval	4
VCR	362	Confidential	Approve (Approver)	5/24/11 15:12	5/24/11 15:30	5/24/11 15:31	NULL	Confidential	Approve	4
VCR	362	Confidential	Approved Close Out	5/24/11 15:31	5/24/11 15:34	5/24/11 15:35	NULL	Confidential	Send On	4
CCR	363	Confidential	Verify Details	4/26/11 22:39	4/28/11 17:10	4/28/11 20:48	NULL	Confidential	Return	4
CCR	363	Confidential	Rework	4/28/11 20:48	4/29/11 15:23	4/30/11 18:58	NULL	Confidential	Submit	4
CCR	363	Confidential	Verify Details	4/30/11 18:58	5/1/11 23:39	5/1/11 23:41	NULL	Confidential	Send On	4
CCR	363	Confidential	Change Request Participants Verification	5/1/11 23:42	5/1/11 23:42	5/1/11 23:47	NULL	Confidential	Send On	4
CCR	363	Confidential	Approve (Site Construction Manager)	5/1/11 23:47	5/2/11 14:28	5/2/11 14:32	5/2/11 23:00	Confidential	Approve	4
CCR	363	Confidential	Approve (Assistant Construction Manager)	5/2/11 14:32	5/2/11 20:18	5/2/11 20:23	5/3/11 23:00	Confidential	Approve	4
FCR	430	Confidential	Review (Engineer)	5/18/11 23:16	5/19/11 14:57	5/19/11 15:44	NULL	Confidential	Send for Review	5

FCR	430	Confidential	Change Request Participants Verification	5/19/11 15:44	5/19/11 15:55	5/19/11 15:55	NULL	Confidential	Send On	5
FCR	430	Confidential	Review (Participants)	5/19/11 15:55	5/20/11 18:31	5/20/11 18:32	5/20/11 23:00	Confidential	Send On	5
FCR	430	Confidential	Review (Participants)	5/19/11 15:55	5/20/11 18:24	5/20/11 18:31	5/20/11 23:00	Confidential	Send On	5
FCR	430	Confidential	Review (Participants)	5/19/11 15:55	5/19/11 17:19	5/19/11 17:25	5/20/11 23:00	Confidential	Send On	5
FCR	430	Confidential	Review (Participants) Warning	5/20/11 23:00	5/24/11 12:47	5/24/11 12:49	NULL	Confidential	Send On	5
FCR	430	Confidential	Review (Participants) Warning	5/20/11 23:00	5/24/11 13:56	5/24/11 13:57	NULL	Confidential	Send On	5
FCR	430	Confidential	Review (Participants) Warning	5/20/11 23:00	5/24/11 23:08	5/24/11 23:18	NULL	Confidential	Send On	5
VCR	752	Confidential	Review (Participants)	7/28/11 17:12	8/4/11 19:17	8/4/11 19:28	NULL	Confidential	Send On	6
VCR	752	Confidential	Review (Participants)	7/28/11 17:12	8/4/11 19:28	8/4/11 19:28	NULL	Confidential	Send On	6
VCR	752	Confidential	Review (Participants)	7/28/11 17:12	7/29/11 19:09	7/29/11 19:12	NULL	Confidential	Send On	6
VCR	752	Confidential	Review (Participants)	7/28/11 17:12	8/3/11 12:19	8/3/11 12:28	NULL	Confidential	Send On	6
VCR	752	Confidential	Approve (Engineer)	8/4/11 19:28	8/22/11 16:56	8/22/11 18:39	NULL	Confidential	Send for Approval	6
VCR	752	Confidential	Approve (Approver)	8/22/11 18:39	8/22/11 19:16	8/22/11 19:19	NULL	Confidential	Approve	6
VCR	752	Confidential	Approver (Manager)	8/22/11 19:19	8/22/11 19:20	8/22/11 19:20	NULL	Confidential	Approve	6
VCR	752	Confidential	Approved Close Out	8/22/11 19:21	8/22/11 19:38	8/22/11 19:43	NULL	Confidential	Send On	6
VCR	1060	Confidential	Verify Details	9/2/11 18:36	9/2/11 19:11	9/2/11 19:13	NULL	Confidential	Return	7
VCR	1060	Confidential	Rework	9/2/11 19:13	9/2/11 20:02	10/19/11 16:55	NULL	Confidential	Submit	7
VCR	1060	Confidential	Verify Details	10/19/11 16:55	10/23/11 19:37	10/23/11 19:37	NULL	Confidential	Send On	7
VCR	1060	Confidential	Change Request Participants Verification	10/23/11 19:37	10/23/11 19:40	10/23/11 19:40	NULL	Confidential	Send On	7
VCR	1060	Confidential	Review (Engineer) Warning	10/26/11 23:00	11/24/11 21:30	11/24/11 21:33	NULL	Confidential	Send for Review	7
VCR	1060	Confidential	Change Request Participants Verification	11/24/11 21:33	11/24/11 21:33	11/24/11 21:34	NULL	Confidential	Send On	7
VCR	1060	Confidential	Review (Participants)	11/24/11 21:34	11/29/11 20:16	11/29/11 20:20	11/26/11 0:00	Confidential	Send On	7
VCR	1060	Confidential	Review (Participants)	11/24/11 21:34	11/25/11 17:08	11/25/11 17:13	11/26/11 0:00	Confidential	Send On	7
CCR	1112	Confidential	Review (Participants)	9/18/11 16:21	9/19/11 16:34	9/19/11 16:37:29	9/20/11 23:00	Confidential	Send On	8
CCR	1112	Confidential	Review (Participants)	9/18/11 16:21	9/18/11 16:29	9/18/11 16:31:47	9/20/11 23:00	Confidential	Send On	8
CCR	1112	Confidential	Review (Participants)	9/18/11 16:21	9/20/11 18:45	9/20/11 18:46:45	9/20/11 23:00	Confidential	Send On	8
CCR	1112	Confidential	Review (Participants)	9/18/11 16:21	9/19/11 13:41	9/19/11 13:42:34	9/20/11 23:00	Confidential	Send On	8
CCR	1112	Confidential	Approve (Engineer)	9/20/11 22:42	9/20/11 22:49	9/20/11 23:01:52	9/22/11 17:00	Confidential	Send for Approval	8
CCR	1112	Confidential	Approved Close Out	9/20/11 23:02	9/21/11 14:10	9/21/11 14:10:54	NULL	Confidential	Send On	8

Appendix B: Change Log

				CHANGE REQUEST, PROJECT CHANGE NOTICE AND CHANGE ORDER LOG												Status Date:	17-May-14
				LEGENDS:												Print Date:	17-May-14
				Approved										Engg. Proc. Contrac	Engg. Proc. Contract Cost	Equipment and Construction	Total cost Impact for Change
Project:				Cancelled/Rejected/Withdrawn		Current cost for Approved changes											
				Potential Changes													
				Total Value Approved/Pending Changes		Potential Forecast impact for changes											
Status:		1. Pending Change Notice [included in Project Potential Forecast]				6. Change Notice Approved and incorporated into Current Project Budget											
		2. Change Notice Rejected/Cancelled				7. Change Request Approved and Incorporated into Current Project Budget											
		3. Corrective Action Taken to Mitigate Change				8. Change Request Rejected/Cancelled											
		4. Change Notice process initiated at ECA															
		5. Change Notice evaluated for scope, schedule and cost impact															
1	2	3	4	5	6	7	8	9	10	11	12	13		14	15	16	17
ECA "PCN" #	Proponent Change #	Date	Initiated by	Description of Change	Status Code	Approved by	Date approved	Budget Type	Status	RFI Ref.	MOC Code	Discipline Code	Sub Area	EP Work Hours	EP Cost	Equip. & Const. Cost for Change	Total Cost for Change
														0	$0	$0	$0
EP CHANGES AFTER CLASS III ESTIMATE																	
A-051	ECO-051	17/May/10	confidential	Pile design for future supports of the Acid Gas Pipe	7	R.B.	11/Jun/10	Forecast	Approved	RFI-80020-057				44	$5,227	$13,968	$19,195
A-052	EC0-052	17/May/10	confidential	Removal of 2 hammer head tower cranes	7	R.B./ J.P.	28/May/10	Forecast	Approved	RFI-80020-046				70	$8,316		$9,432
A-053	ECO-053	17/May/10	confidential	Mirror the first 2 modules of N-S pipe rack	7	R.B./ J.P.	28/May/10	Forecast	Approved	RFI-80020-056				340	$40,392		$45,814
A-054	ECO-054	20/May/10	confidential	Emergency Genset Piping deletion	7	R.B./ J.P.	28/May/10	Forecast	Approved	RFI-80020-044				-42	($4,882)	($52,333)	($57,215)
A-057	ECO-057	28/Jul/10	confidential	Vent Stack height change and Internal coating of vent stack and Piping	7			Forecast	Approved	RFI-80020-061				270	$32,076	$272,241	$304,317
A-058	ECO-058	16/Jun/10	confidential	Site Security Fence	7	A.P./J.P.	02/Jul/10	Forecast	Approved					100	$10,260	$400,932	$411,192
A-059	ECO-059	16/Jun/10	confidential	Camp Site Security Fence Rev. 1 (23-Jun-10)	7	R.B./J.P.	16/Jul/10	Forecast	Approved					48	$5,056	$319,443	$324,499
A-060	ECO-060	18/Jun/10	confidential	Temporary Construction facility	7	A.P./J.P.	02/Jul/10	Forecast	Approved					200	$21,195	$124,436	$145,631
A-061	ECO-061	13/Jul/10	confidential	Unit Fuel Gas ESD and Blowdown Valves	7	A.P./J.P.	29/Jul/10	Forecast	Approved					400	$47,520	$226,543	$274,063

Appendix C: Change Request Form

CHANGE REQUEST

Project: *Name deleted due confidentiality* **Job No.**

Location: d-76-J/94-P-4 **Doc. No.** xxxx-x-xxx-xCR-xxxxx-002 Rev.:

☐ ENGINEERING ☐ VENDOR ☐ FIELD ☐ CONTRACT ☐ *name deleted due to confidentiality* ☐

SECTION: 1 **MOC Code:** **Ref: RFI No:** CGP1 - - - RFI - -

Title: **Discipline:** **Date:**

Prepared By: **Sub Area:** **Ref PCN No:**

Description of Change:

Reason for Change / Justification:

Is there an impact on the cost? ☐ Yes ☐ No

Engineering required: ☐ Yes ☐ No

Discipline	Hours	% of Total	Cost	PRISM Cost Code (by EP)
B_Process			$	
C_Mechanical Equipment			$	
I_Indirects			$	
L_Piping			$	
N-Insulation and Glycol HT			$	
Q- Piling and Foundation			$	
M- Structural Steel			$	
R- Buildings Including HVAC			$	
S- Civil Site Work			$	
X- Painting/Coatings			$	
J- Instrumentation and Control			$	
P- Electrical			$	
Z- Tracing (EHT)			$	
Total Hours				
Total Engineering:	$		$	
Total Engineering Expenses:	$			

Cost Breakup: (See attached cost estimate for details).

Total Direct Construction Cost	$			
Total Direct Vendor Cost	$			
Total Indirect Field cost	$			
Home Office Eng. Cost	$			
Camp and Transportation	$			
Owners Cost	$			
Contingency Cost	$			
1% Overhead Fee	$			
Total:	$			

Schedule Impact: (see attached detailed schedules) **Is there any impact on the schedule?** ☐ Yes ☐ No

Final Completion Date:

Construction Schedule:

	CHANGE REQUEST	

Project: *Name deleted due confidentiality* **Job No.** | |

Location: d-76-J/94-P-4 **Doc. No.** xxxx-x-xxx-xCR-xxxxx-002 Rev.:

Commissioning Schedule: [ ]

Originator	||		||
Project Manager	| |		| |
	Print Name	*Signature*	*Date*

SECTION 2 [This section will be filled by EP contractor where originator is Vendor or Construction team]

Validation Comments: |

|

Project Engineer	[ ]		[ ]
Project Manager	[ ]		[ ]
	Print Name	*Signature*	*Date*

SECTION 3 [This section will always be completed by XXXX PMT]

Process Hazard Assessment Required: ☐ Yes ☐ No

Change Order Disposition:

☐ Change rejected; take no further action ☐ Revise and resubmit

☐ Proceed with change & incorporate into current Procurement Plan, Project Budget and Schedule as directed by transferring funds from ☐ Design Development ☐ Contingency ☐ Management Reserve

Signature Requirement:

☐ Required Lead Project Engineer Signature only

☐ Required Project Manager Signature only

☐ Required approval from higher authority as per approval matrix

Comments: [

]

Approvals:

Encana Responsible Engineer	[ ]		[ ]
Encana Lead Project Engineer	[ ]		[ ]
Encana Assistant Project Manager	[ ]		[ ]
Encana Required Approval Authority	[ ]		[ ]
	Print Name	*Signature*	*Date*

Instructions to fill out the form:

1. **Appropriate box will be checked by the originator for Engineering, Vendor, Field or Contract.**
2. **Section 1 will be completed by originator with signature from Project Engineer and Project Manager.**
3. **Section 2 will be completed by EP contractor for validation of cost, schedule & risk impact.**
4. **Section 3 will be completed by XXXX PMT.**
5. **Additional sheet for the breakup cost estimate will be attached if required.**
6. **Job number field is the Job number of the originating company.**

	CHANGE REQUEST	

Project:	*Name deleted due confidentiality*	Job No.	
Location:	d-76-J/94-P-4	Doc. No.	xxxx-x-xxx-xCR-xxxxx-002 Rev.:

7. **Document number will be referred to as the ECR, VCR, FCR or CCR number and will be provided as XXXX-Discipline code-Sub area-VCR/ECR/FCR-PO# or Template or Contract # - sequential number (e.g XXXX-J-201-VCR-60040-001).**

XXXX	**XXXX**
J	**XXXX Discipline Code**
201	**Sub area**
VCR	**Vendor Change Request**
60040/SO.00024	**Purchase Order number/Service Order Number**
001	**Sequential number (Note: Sequential number for FCR will start from "0001")**

8. **Document numbers for Change Request between EP Contractor-XXXX will be issued and maintained by EP contractor to avoid duplication.**
9. **Document numbers for all other Change Request will be issued and maintained by originator (Vendors, Construction contractors or module yard fabricators) to avoid duplication.**

Appendix D: Project Change Notice Form

PROJECT CHANGE NOTICE (PCN)
(Ref: XXXX-A-000-PRC-00010)

Appendix "D" Rev.0_29-Apr-2010

To:	(Lead Project Engineer)	Date Prepared:	
cc:	(Responsible Engineer)	Project No.:	
cc:	(Change Mgmt. Coordinator)	Change Order No.:	
From:	(Originator)	Rev. No.:	0

Project : *name deleted due to confidentiality*
Location : *name deleted due to confidentiality*

☐ Engineering Change Order (ECO) No:
☐ Vendor Change Order (VCO) No:
☐ Contract Change Order (CCO) No:
☐ Field Change Order (FCO) No:

Title of Change

Description of Change

Reason for Change

References or Backups

Is risk evaluation required?	☐ Yes	☐ No	☐ N/A
Is there cost and schedule impact ?	☐ Yes	☐ No	☐ N/A
Is it operable?	☐ Yes	☐ No	☐ N/A
Is it maintainable?	☐ Yes	☐ No	☐ N/A
Does it meet XXXX Specs?	☐ Yes	☐ No	☐ N/A

Total Cost Impact
Order of Magnitude [+/- 15%]
[including EP costs]

EP Impact

EP Hours	0	Hours
EP Costs	$0	$CND

Schedule Impact
[What scheduled milestones or deliverables are affected?]

Attach additional documentation if required

Change Order Disposition

☐ Change rejected; take no further action
☐ Proceed with change and incorporate it into current Project Budget from Design Development allowance
☐

	Print Name	Signature	Date
Project Director:			
Project Manager:			
Engineering Manager			
Project Controls Manager:			
Procurement Manager:			
Contracts Manager:			
Construction Manager:			
Quality Manager:			

Appendix E: RFI Log

				RFI LOG													
Project:						Approved			Potential Trends/Changes					Reference Procedure:			
Location:						Rejected			Need clarification					Data date:			Print Date:
Contract or PO number	RFI #	RFI Description	Originator	RE	From	To	Change Order required (Yes/No)	Reference ECO/FCO /VCO No.	RFI Code	Estimted Cost Impact	Potential Schedule Impact	Discipline Code	Date Submitted	Required date for resolution (dd/mm/yy)	Date Approved/ resolved (dd/mm/yy)	STATUS Approved, NTP, Rejected, Pending	Comments

Appendix F: Project Roles and Responsibilities from the Owner's perspective

Project Role	Responsibilities
Business Sponsor	The role of the Business Sponsor is to represent the project and ensure that the project deliverables meet the objectives of the project and deliver value to the organization. Specific duties include: • Funds the project • Justifies the expected benefits and approves the project costs • Ensures business objectives and scope are clearly defined • Approves the project charter • Approves project budget, schedule and scope changes • Champions the project to the organization • Liaises with senior management • Commits to provide the needed business resources to the project • Resolves issues that are escalated • Formally accepts the completed project deliverables • Accountable for ensuring the delivery of the project's expected benefits • Commits to provide the needed funds to sustain the solution
Business Lead (Subject matter Expert for RFI/CR and PCN)	The Business Lead represents the primary users of the IT solution; and is accountable to the Business Sponsor to ensure that the project delivers on business needs, drivers, strategies and associated functional requirements. Specific duties include:

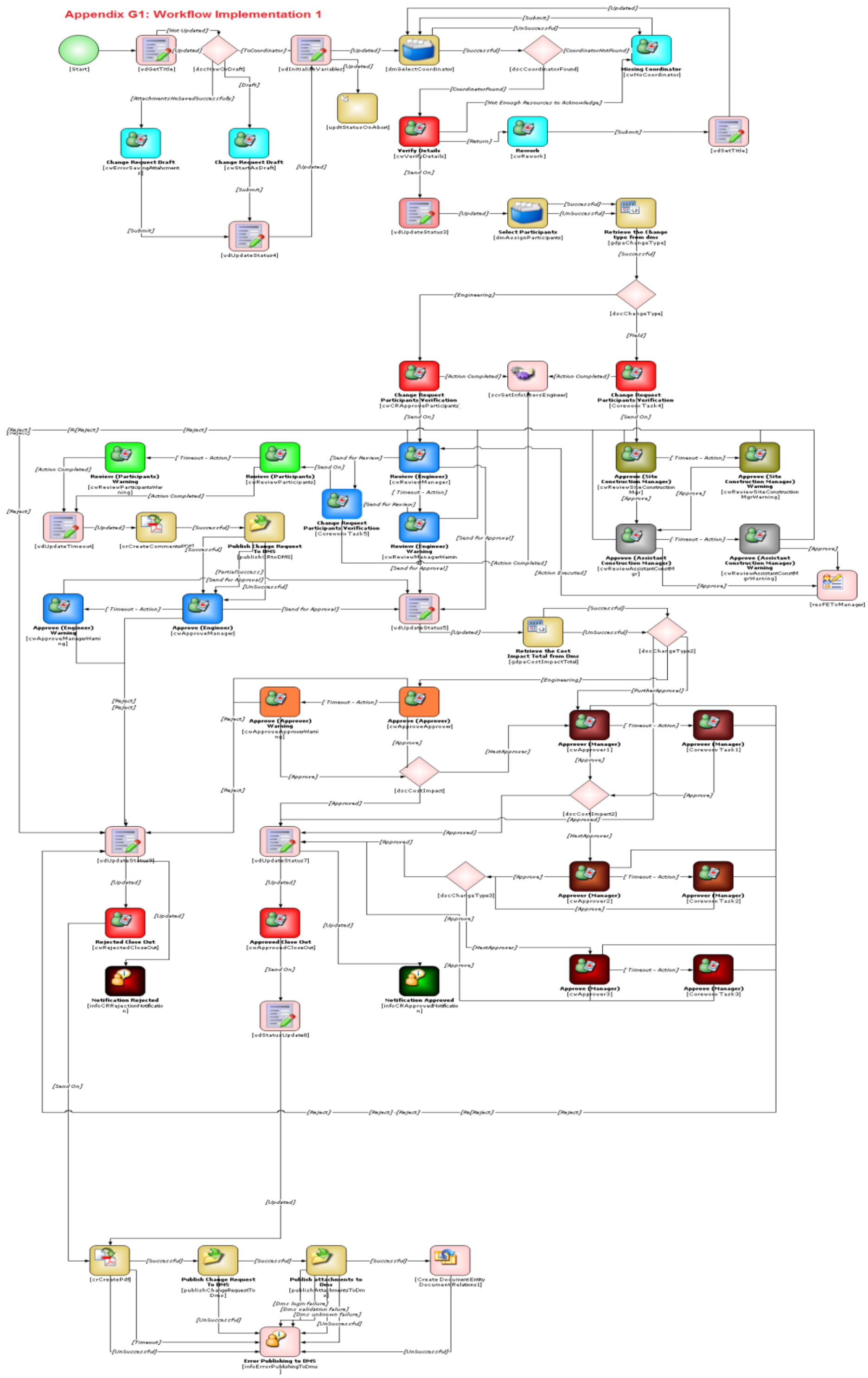
Project Role	Responsibilities
	• Provides business knowledge and expertise to the project team • Provides appropriate functional requirements • Reviews and approves deliverables on behalf of the Business Sponsor • Maintains awareness of project schedule and progress • Ensures the delivered solution meets business objectives • Ensures user group is prepared and trained for delivered solution • Approves business solutions within the approved scope of the project and provides business sign-off and acceptance • Determines business resource load and performance and ensures business resources are delivering according to the project plan
Working Committee	This committee is made up of representatives from the key stakeholder groups, and acts as an advisory board providing in-depth business knowledge to the project team. Consistent attendance and participation in the committee is a critical success factor for the role. The Working Committee focuses on the details of a project. Specific duties include: • Reaches consensus and makes recommendations in a timely manner on behalf of the organizations the members represent • Acts as the first line of assistance for the project team • Provides the necessary background and authority to remove roadblocks that may arise • Communicates project progress and decisions back to

Project Role	Responsibilities
	their functional areas. • Accountable to the project team and their functional areas for the decisions made • Resolves escalating issues or conflicts within their span of control.
Project Manager	The Project Manager is responsible for delivering a quality product on time and within the budget and scope constraints approved by the Business Sponsor. Specific duties include: • Prepares project charter • Develops and maintains project plans and budget • Staffs project with support from the Business Sponsor and IT Lead • Clearly defines project team work expectations • Monitors project team performance • Monitors and controls the overall execution of the project delivery • Manages and escalates issues and risks as appropriate • Manages change requests • Keeps the Business Sponsor informed of project status and any key issues or decisions that are required • Chairs the Working Committee • Facilitates interaction between the project sub-teams • Has overall responsibilities for procurement and vendor management to ensure EnCana's best practices are followed • Plans project celebrations

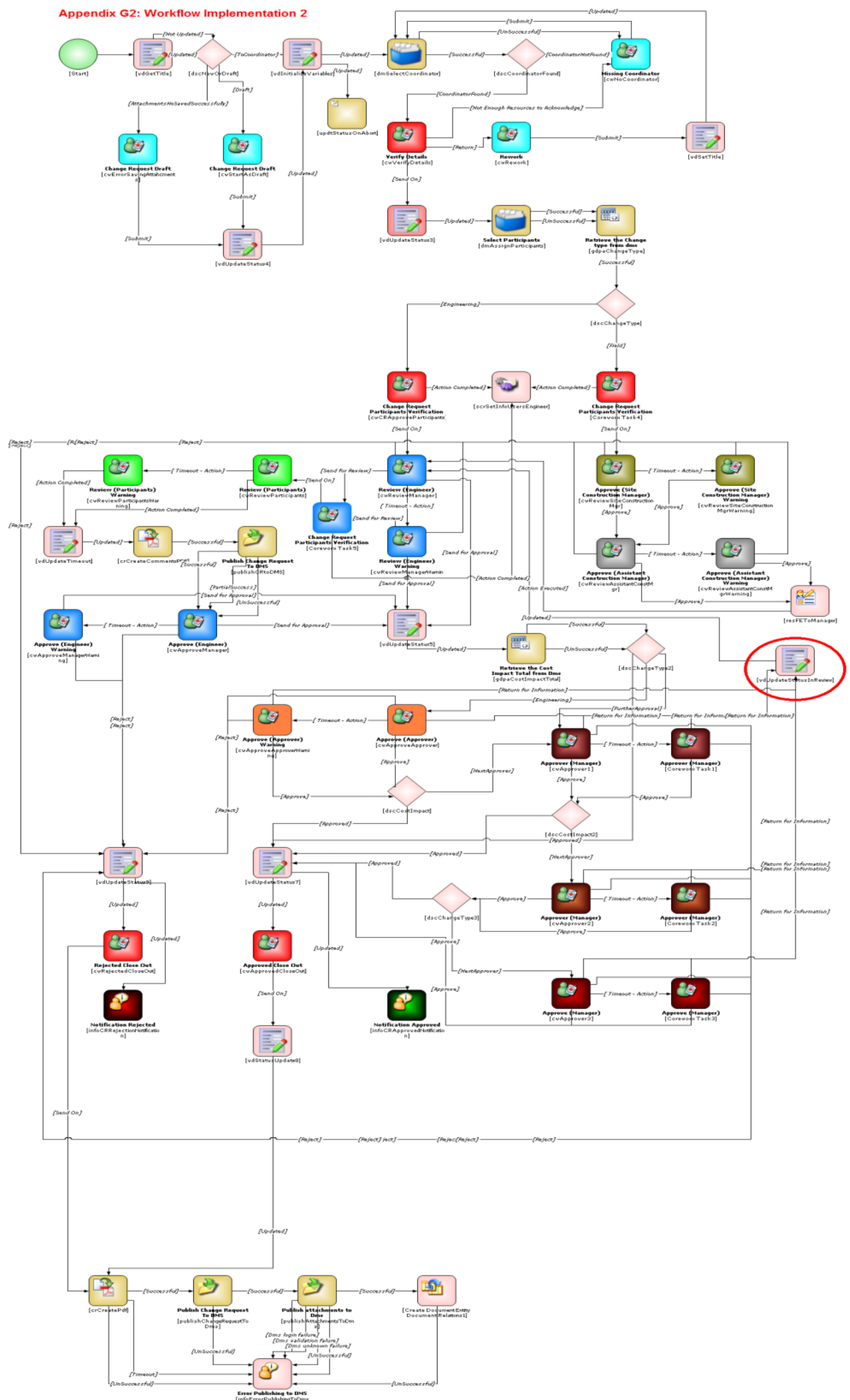
Project Role	Responsibilities
Business Analyst	The role of the Business Analyst is to liaise between the business and IT. Specific duties include: • Identifies and scopes business opportunities • Understands functional requirements and can translate into a technical solution • Collaborates in the creation of and signs off on the functional specification • Develops, facilitates and signs off on system testing, and coordinates user acceptance testing • Oversees the development and execution of training • Transitions knowledge from the project team to the business and support organization • Facilitates business process changes to leverage new solutions
Technical Team Lead	The Technical Team Lead is responsible for the design of the technical solution; and provides technical leadership and direction to the project. Specific duties include: • Manages detailed project activities from a technical perspective • Provides leadership to technical resources • Engages the infrastructure team and Solutions Architecture to ensure the application meets Project's current systems infrastructure requirements • Tracks technical events • Analyzes business processes and technical information related to the functional requirements • Liaises with the infrastructure team

Project Role	Responsibilities
	• Liaises with other project teams • Manages interface activities • Ensures sustainment processes are in place • Coordinates vendor activities
Business Change Lead	The Business Change Lead is an ambassador for change within the Project team and represents the wider stakeholders in priority setting and quality assurance. Specific duties include: • Ensure an inclusive stakeholder communication plan • Focal point for stakeholder feedback • Ensures changes to business process are well defined and communicated • Ensures relevant standards documentation is updated • Drive change in internal and external stakeholder groups • First point of escalation for business process related issues • Supports project manager I achieving critical success factors • Promotes and the achievement of the benefits of the solution

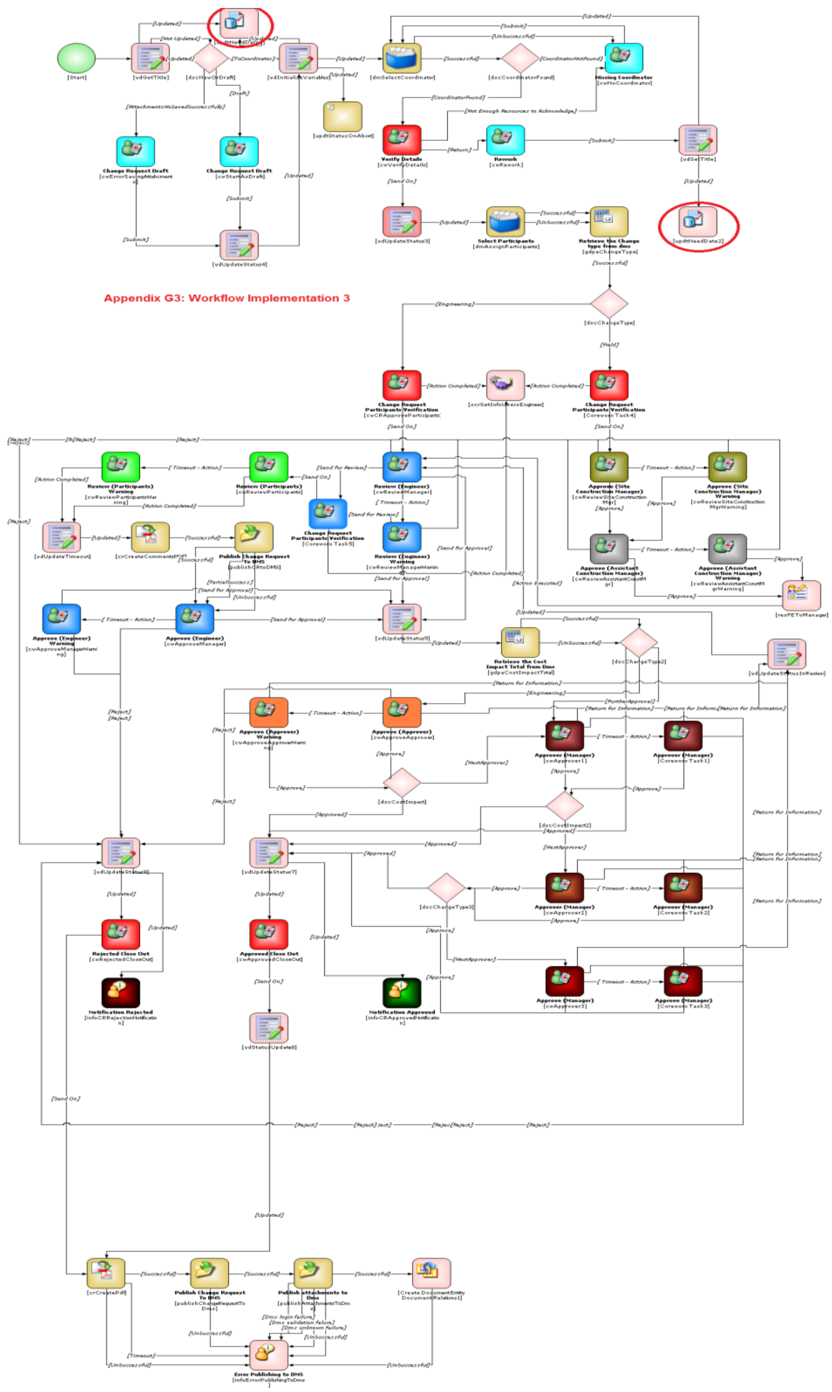
Appendix G1: Change request workflow implementation 1



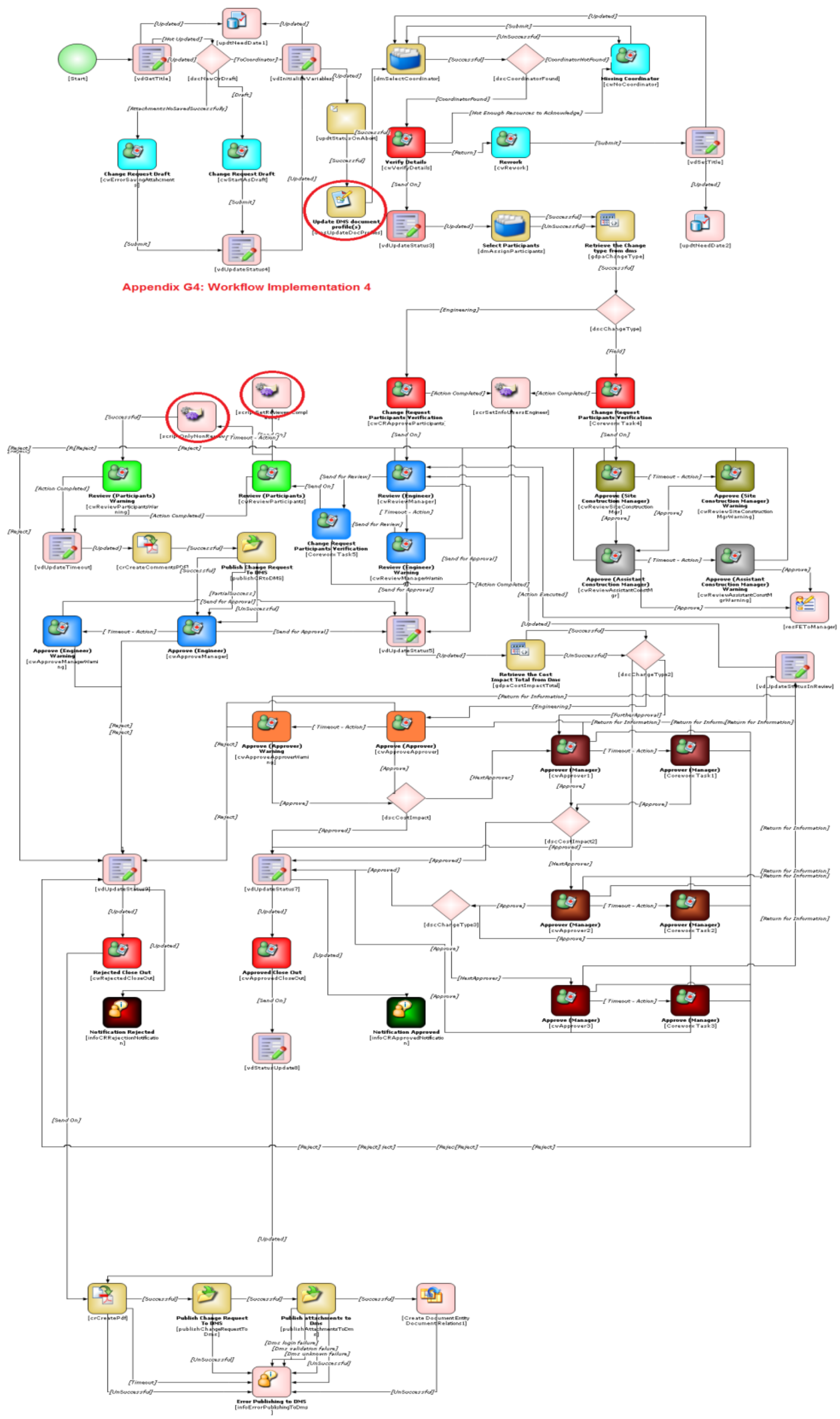
Appendix G2: Change request workflow implementation 2



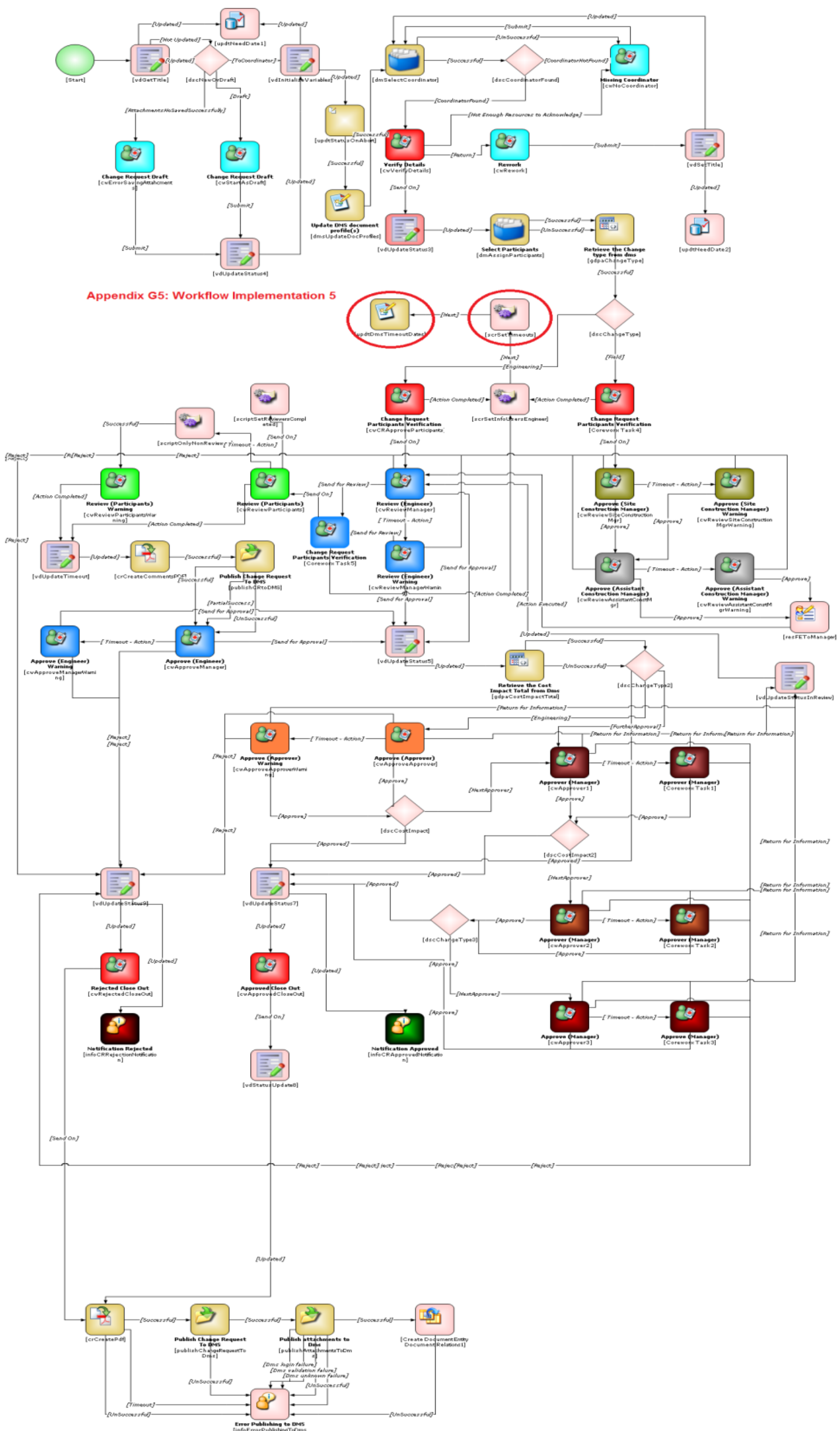
Appendix G3: Change request workflow implementation 3



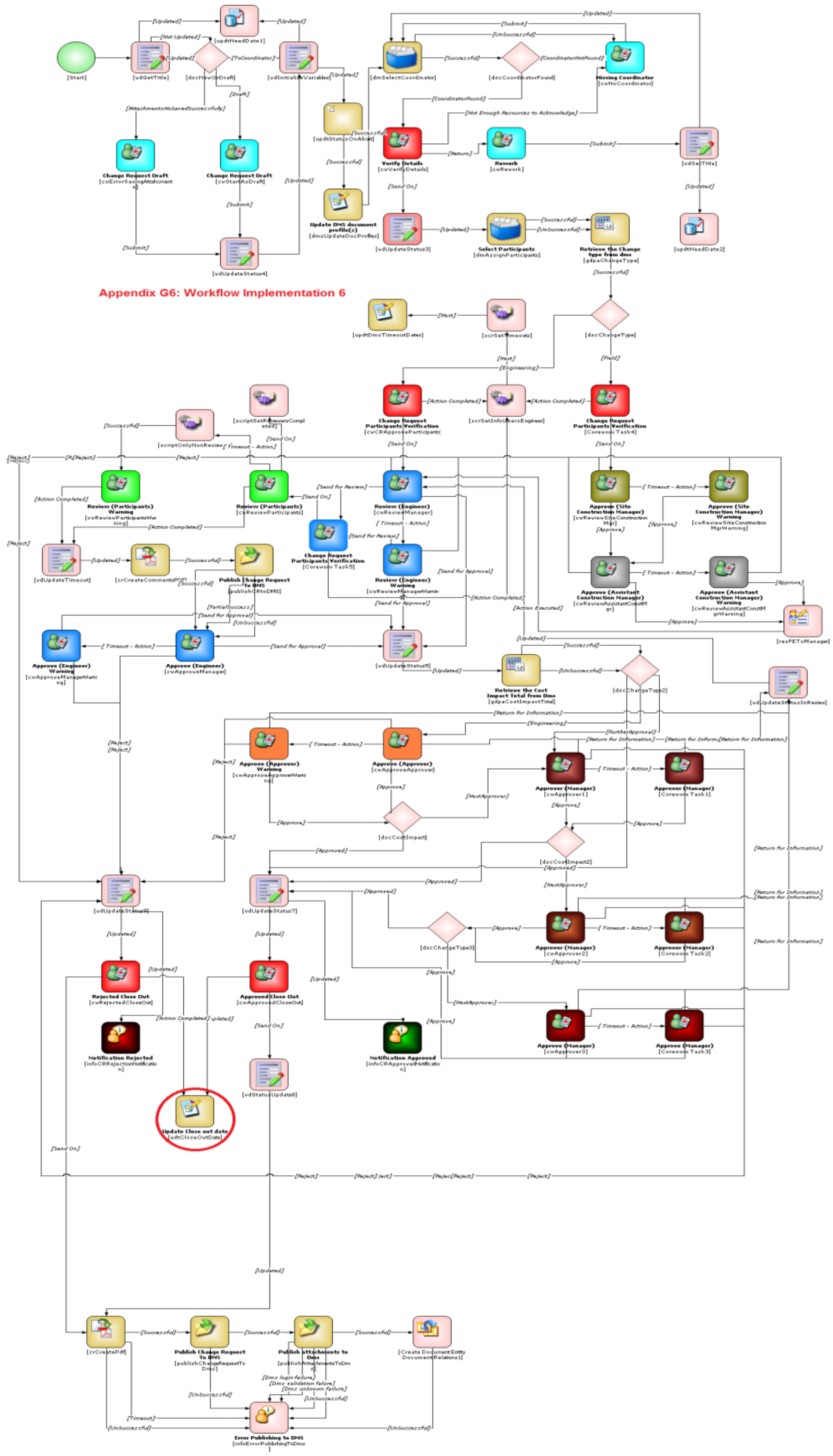
Appendix G4: Change request workflow implementation 4



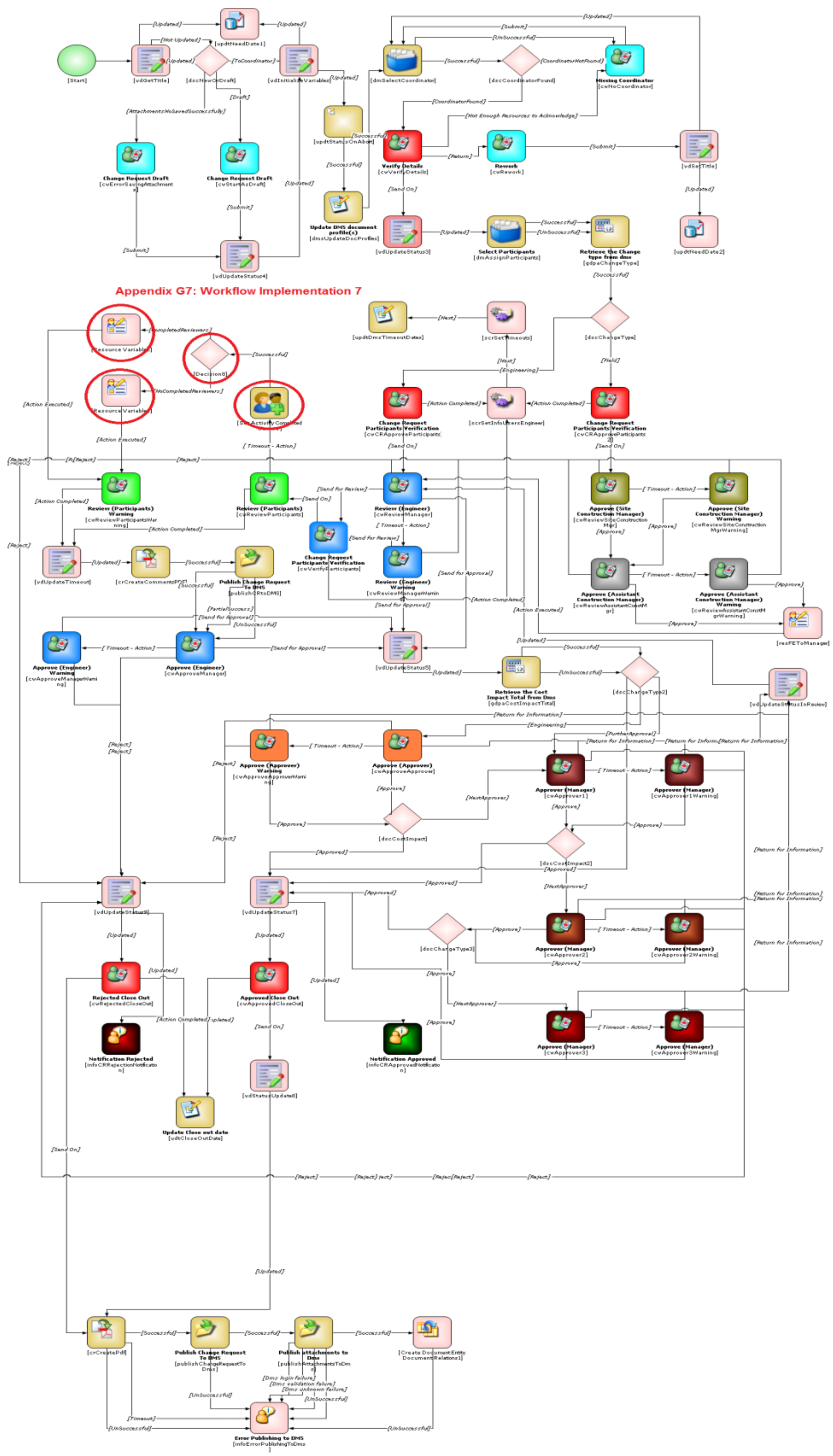
Appendix G5: Change request workflow implementation 5



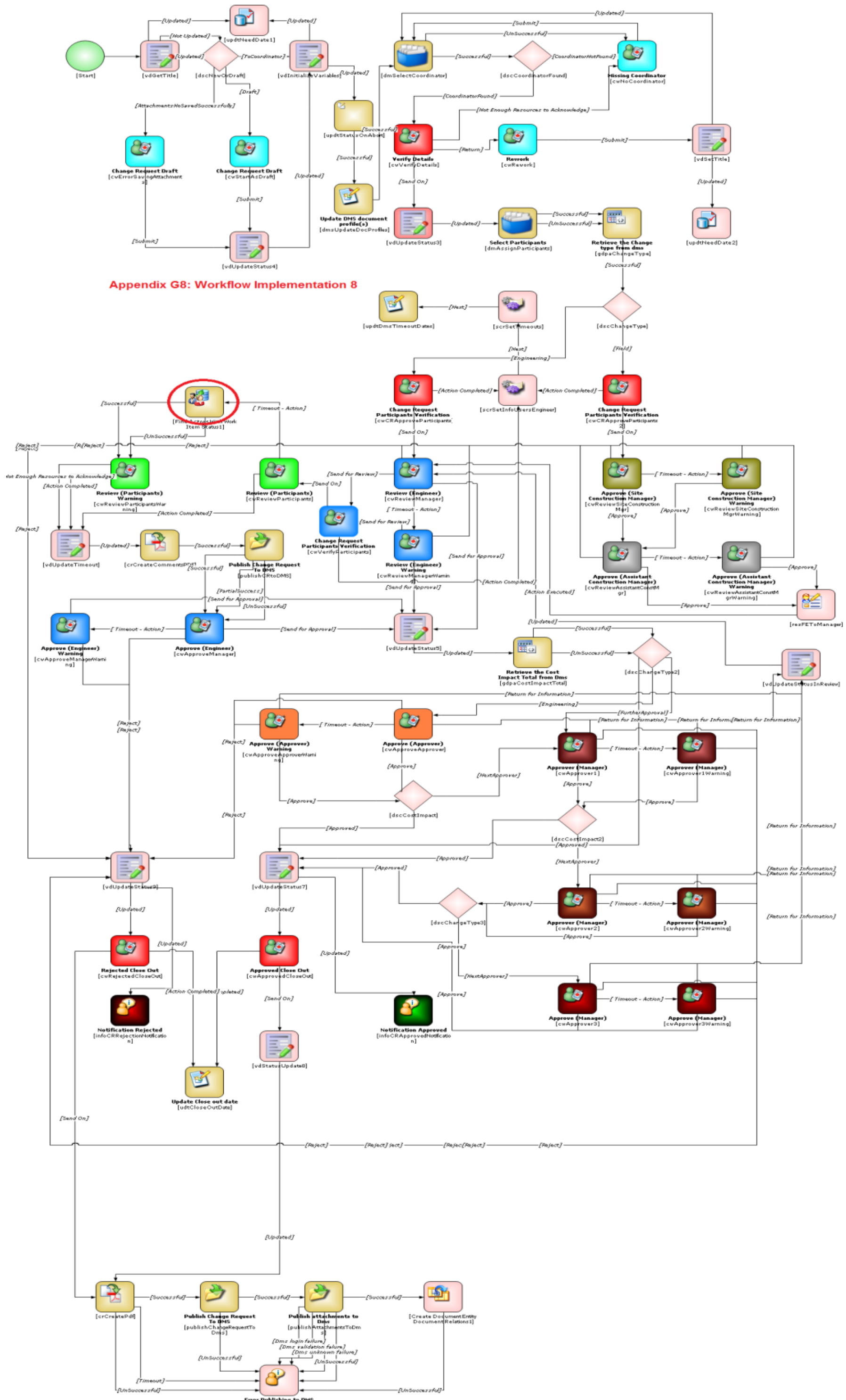
Appendix G6: Change request workflow implementation 6



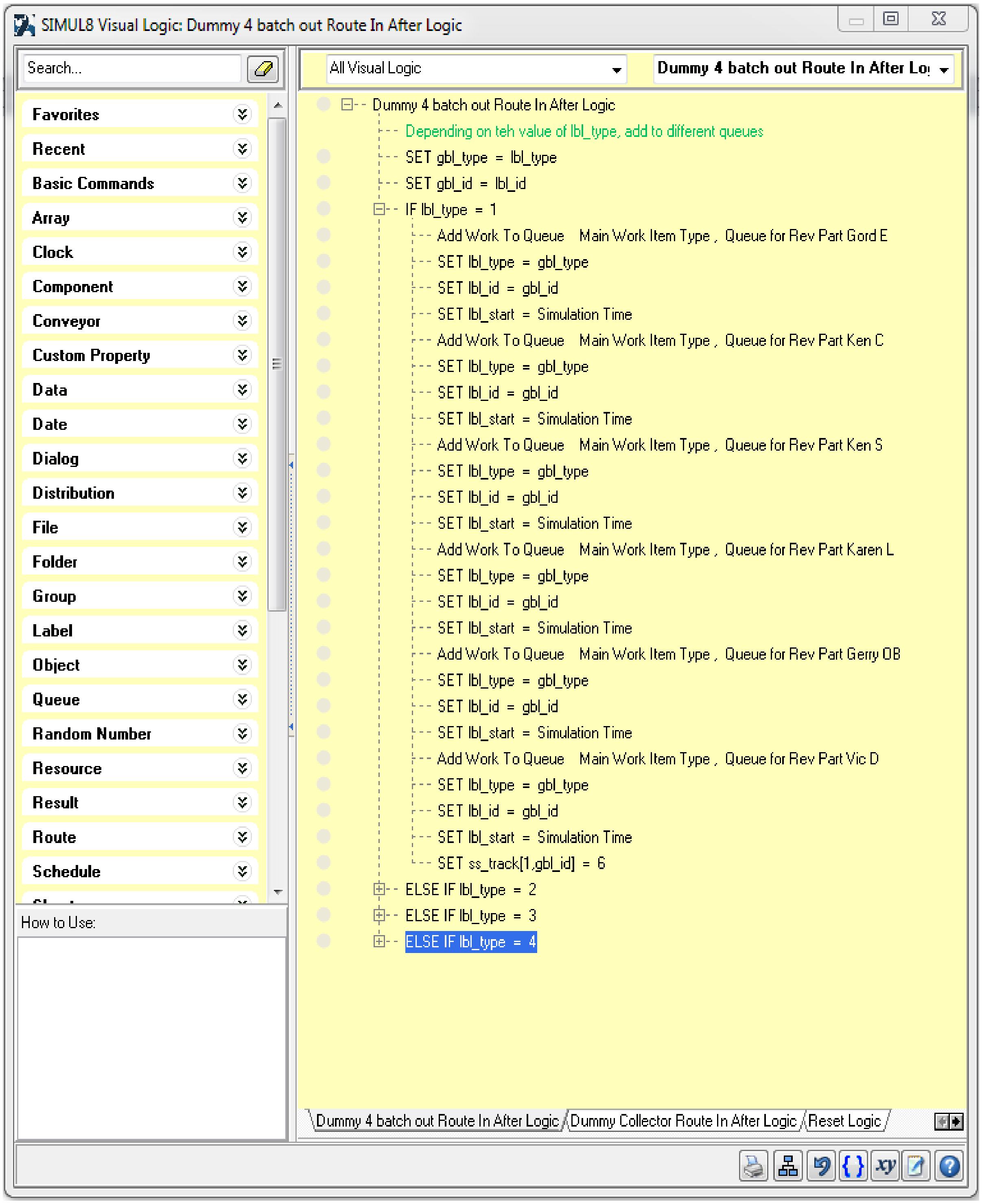
Appendix G7: Change request workflow implementation 7



Appendix G8: Change request workflow implementation 8



Appendix H: Coding in Visual Logic for “Review Participants”



Appendix I: The arrival rate of change requests (OGP2)

Created date time	Inter-arrival time	
Wed 4/13/2011 10:34	0:00:00	0
Wed 4/13/2011 10:42	0:07:48	0.13
Wed 4/13/2011 16:50	6:08:09	6.14
Fri 4/29/2011 6:07	133:17:05	133.28
Wed 5/4/2011 16:57	46:50:01	46.83
Thu 5/5/2011 15:47	10:49:54	10.83
Fri 5/6/2011 13:17	9:30:31	9.51
Tue 5/10/2011 15:19	26:01:59	26.03
Wed 5/11/2011 12:20	9:01:10	9.02
Fri 5/13/2011 11:11	22:50:06	22.83
Mon 5/16/2011 16:17	17:06:14	17.10
Thu 5/19/2011 9:43	29:26:44	29.45
Wed 5/25/2011 9:44	48:00:17	48.00
Wed 5/25/2011 14:19	4:35:22	4.59
Wed 5/25/2011 14:58	0:39:04	0.65
Wed 5/25/2011 16:34	1:36:16	1.60
Thu 5/26/2011 7:32	2:57:21	2.96
Thu 5/26/2011 9:18	1:45:52	1.76
Thu 5/26/2011 10:29	1:11:15	1.19
Thu 5/26/2011 14:11	3:41:56	3.70
Thu 5/26/2011 14:42	0:31:08	0.52
Thu 5/26/2011 15:06	0:24:11	0.40
Tue 5/31/2011 8:55	29:48:47	29.81
Tue 5/31/2011 14:50	5:54:46	5.91
Thu 6/2/2011 16:28	25:38:18	25.64
Fri 6/3/2011 11:17	6:48:53	6.81
Fri 6/3/2011 11:26	0:08:58	0.15
Fri 6/3/2011 11:32	0:06:08	0.10
Wed 6/8/2011 14:15	38:42:58	38.72
Fri 6/17/2011 10:46	80:31:18	80.52
Fri 6/17/2011 13:13	2:27:09	2.45
Wed 6/22/2011 10:45	33:31:44	33.53
Wed 6/29/2011 16:28	65:42:39	65.71
Wed 6/29/2011 17:29	1:01:36	1.03
Thu 6/30/2011 11:22	5:52:39	5.88
Tue 7/12/2011 13:27	2:23:25	2.39
Tue 7/12/2011 13:34	0:07:23	0.12
Wed 7/20/2011 8:27	66:52:11	66.87
Wed 7/20/2011 14:36	6:09:18	6.15
Thu 7/21/2011 12:06	9:29:46	9.50
Thu 7/21/2011 17:55	5:49:05	5.82
Fri 7/22/2011 11:18	5:23:22	5.39
Tue 7/26/2011 10:56	23:37:55	23.63
Wed 7/27/2011 13:28	14:31:56	14.53
Wed 8/3/2011 8:29	55:00:40	55.01
Fri 8/5/2011 7:44	23:15:36	23.26
Tue 8/9/2011 8:55	25:11:14	25.19
Wed 8/10/2011 11:42	14:46:20	14.77
Wed 8/10/2011 12:55	1:13:05	1.22
Wed 8/10/2011 13:05	0:10:03	0.17
Wed 8/10/2011 13:07	0:02:08	0.04
Wed 8/10/2011 13:28	0:20:44	0.35
Wed 8/10/2011 16:07	2:38:51	2.65
Wed 8/10/2011 16:18	0:11:19	0.19
Thu 8/11/2011 17:30	13:11:42	13.20
Mon 8/15/2011 17:26	23:56:11	23.94
Tue 8/16/2011 15:59	10:32:57	10.55
Wed 8/17/2011 13:59	10:00:19	10.01
Thu 8/18/2011 17:13	15:13:33	15.23
Fri 8/19/2011 10:16	5:03:46	5.06
Mon 8/22/2011 14:12	15:55:30	15.92
Fri 8/26/2011 4:33	38:21:30	38.36
Fri 8/26/2011 5:17	0:43:23	0.72
Mon 8/29/2011 8:11	14:54:30	14.91
Thu 9/1/2011 17:04	44:52:45	44.88
Wed 9/7/2011 7:39	38:35:14	38.59
Mon 9/12/2011 11:48	40:08:33	40.14
Wed 9/14/2011 12:00	24:11:43	24.20
Thu 9/15/2011 7:38	7:38:08	7.64
Lambda: 1/E(X)	**0.0534**	

Appendix J: Instances' duration in each workflow implementation (OGP1)

Workflow Implementation 2									
WF_ID	Instance Duration	Instance Effective Duration	Instance Waiting Duration	WF_ID & Activity Display Name	sum of review waits	Review times	max review time	total waits	Modified Instance Duration
35	142:20:27	16:38:15	53:41:49	35Verify Details	0:00:00		0:00:00	53:41:49	70:20:03
36	141:47:51	16:59:48	2.04	35Change Request Participants Verification(CW task4)	0:00:00		0:00:00	49:01:03	66:00:50
42	432:11:36	4:15:21	6.87	35Approve (Site Construction Manager)	160:16:53		89:28:42	235:45:37	169:12:47
44	210:55:00	13:24:54	2.73	35Approve (Assistant Construction Manager)	0:00:00		0:00:00	65:29:21	78:54:15
46	189:59:51	22:31:45	2.01	35Review (Engineer)	70:08:28		24:02:14	94:21:42	70:47:13
48	689:21:08	133:57:42	5.27	35Approved Close Out	156:04:28		59:29:30	223:09:06	260:31:50
53	14:06:01	1:44:54	0.01	36Verify Details	0:00:00		0:00:00	0:20:55	2:05:49
54	outlier			36Change Request Participants Verification(CW task4)					
56	358:22:04	24:27:20	4.69	36Approve (Site Construction Manager)	38:07:09		15:20:43	135:26:52	137:07:46
57	647:39:35	55:21:57	9.34	36Approve (Assistant Construction Manager)	130:40:53		107:50:49	246:54:11	279:26:05
58	194:26:20	12:50:04	2.57	36Review (Engineer)	0:00:00		0:00:00	61:35:13	74:25:17
59	444:20:49	2:27:34	5.83	36Approved Close Out	140:28:26		63:51:24	216:31:15	142:21:48
60	444:08:23	6:07:07	5.89	42Change Request Draft	256:53:33		70:21:59	327:47:34	147:23:08
61	644:20:16	5:13:20	8.76	42Verify Details	387:13:11		133:51:30	463:35:38	215:27:16
62	442:01:55	20:26:34	5.00	42Rework	263:46:31		72:19:00	311:25:18	140:24:21
63	677:07:12	8:12:37	9.50	42Verify Details	387:33:37		133:52:25	481:47:37	236:19:03
64	442:01:33	5:34:34	5.83	42Rework	148:01:15		70:23:11	217:36:31	145:33:00

65	644:01:56	0:13:11	8.77	42Verify Details	386:56:08		133:56:18	463:32:35	210:45:56
66	441:42:19	0:16:09	5.85	42Rework	266:19:16		74:38:04	331:58:40	140:33:37
67	441:33:52	23:51:04	5.06	42Verify Details	151:28:18		70:18:54	202:35:47	145:17:27
68	644:39:06	18:15:38	8.60	42Change Request Participants Verification(Eng)	105:12:32		63:34:28	248:07:33	224:45:07
69	441:39:42	10:48:38	5.95	42Review (Engineer)	99:08:47		57:34:23	184:27:18	153:41:33
70	441:39:30	13:39:33	5.84	42Approve (Approver)	105:05:35		63:31:14	181:38:27	153:43:39
71	**outlier**			42Approver (Manager)					
72	839:47:12	232:49:29	7.86	42Review (Engineer)	245:28:47		108:00:52	325:59:51	421:21:25
73	437:38:40	3:49:26	6.09	42Change Request Participants Verification(CW task5)	265:31:38		108:16:39	303:18:33	149:53:00
74	114:47:45	0:42:32	1.25	42Review (Participants)	0:00:00	7:09:58	0:00:00	30:04:55	30:47:27
76	135:23:11	7:06:26	1.34	42Review (Participants)	0:00:00	19:29:28	0:00:00	32:16:24	39:22:51
78	520:04:36	43:13:18	5.87	42Review (Participants)	127:44:39	3:15:23	63:42:57	205:01:11	184:12:47
86	364:48:40	10:07:56	4.79	42Review (Participants)	109:36:30	89:28:42	63:46:01	160:48:21	125:05:48
Average									**150:33:58**

Workflow Implementation 3									
WF_ID	Instance Duration	Instance Effective Duration	Instance Waiting Duration	WF_ID & Activity Display Name	sum of review waits	Review times	max review time	total waits	Modified Instance Duration
88	346:01:37	0:42:58	129:28:23	88Verify Details	318:13:11		106:21:09	341:20:26	130:11:21
96	24:06:54	0:12:04	11:54:06	88Change Request Participants Verification	0:00:00		0:00:00	11:54:06	12:06:10
100	42:44:29	9:46:27	8:57:15	88Review (Engineer)	0:00:00		0:00:00	8:57:15	18:43:42
102	381:11:40	123:38:54	12:47:37	88Change Request Participants Verification	0:00:00		0:00:00	12:47:37	136:26:31
104	1191:03:05	520:07:06	189:38:55	88Review (Participants)	189:43:56	26:30:51	70:54:09	308:28:41	709:46:00
105	61:37:12	0:07:06	25:29:10	88Review (Participants)	0:00:00	50:45:10	0:00:00	25:29:10	25:36:16
106	71:26:23	1:12:08	34:12:37	88Review (Participants)	0:00:00	50:40:32	0:00:00	34:12:37	35:24:45
107	502:29:49	2:32:50	155:37:35	88Review (Participants)	251:27:23	16:03:13	117:17:25	289:47:32	158:10:25
108	499:01:40	79:23:19	172:38:50	88Review (Participants)	109:42:22	67:26:19	63:37:05	218:44:07	252:02:09
112	102:04:18	0:03:53	43:24:13	88Review (Participants)	0:00:00	0:25:57	0:00:00	43:24:13	43:28:06
115	471:56:46	0:30:27	171:43:30	88Review (Participants)	409:08:20	106:21:09	124:24:46	456:27:04	172:13:57
116	outlier			88Approve (Engineer)					
117	361:09:31	0:23:20	132:19:28	88Approve (Approver)	191:28:09		100:18:14	223:29:23	132:42:48
120	22:11:26	0:47:18	9:23:06	88Approved Close Out	0:00:00		0:00:00	9:23:06	10:10:24
123	21:40:55	0:39:41	9:00:20	96Verify Details	0:00:00		0:00:00	9:00:20	9:40:01
124	503:37:52	28:32:04	153:55:59	96Change Request Participants Verification	220:09:58		99:13:51	274:52:06	182:28:03
125	503:21:01	3:53:16	148:45:02	96Review (Engineer)	229:49:15		106:52:52	271:41:24	152:38:18
126	502:51:34	85:41:14	154:10:52	96Approve (Approver)	211:31:50		106:58:45	258:43:58	239:52:06
127	472:02:14	41:59:17	143:51:06	96Approved Close Out	243:41:22		109:54:04	277:38:23	185:50:23
128	469:24:22	24:18:25	141:21:20	100Verify Details	307:13:41		113:32:42	335:02:19	165:39:45

129	267:05:36	1:15:56	86:01:19	100Change Request Participants Verification	172:20:09		45:07:11	213:14:16	87:17:15
131	348:30:10	40:23:08	80:20:37	100Review (Engineer)	111:22:03		34:58:06	156:44:34	120:43:44
133	410:01:29	13:33:50	134:10:17	100Approve (Approver)	176:27:12		100:20:43	210:16:46	147:44:07
134	409:32:26	6:42:00	127:30:08	100Approved Close Out	191:06:54		100:08:20	218:28:42	134:12:08
135	344:39:52	0:15:33	127:25:38	102Verify Details	192:26:01		100:09:05	219:42:33	127:41:10
136	344:23:07	1:00:38	127:11:21	102Rework	191:50:03		100:16:32	218:44:52	128:12:00
138	83:13:14	0:05:29	30:19:06	102Verify Details	0:00:00		0:00:00	30:19:06	30:24:35
139	337:02:40	5:06:41	123:11:36	102Change Request Participants Verification	166:56:24		99:25:30	190:42:30	128:18:18
140	336:19:10	0:17:44	125:36:02	102Review (Engineer)	167:28:17		100:06:06	192:58:13	125:53:47
141	406:56:13	0:23:13	128:05:08	102Rejected Close Out	190:05:37		99:24:07	218:46:38	128:28:21
142	250:19:36	0:39:37	87:35:36	104Verify Details	108:18:38		57:33:20	138:20:54	88:15:13
143	450:18:49	14:10:31	137:19:38	104Change Request Participants Verification	183:36:43		106:57:25	213:58:55	151:30:09
147	480:19:26	5:40:40	141:33:58	104Review (Engineer)	197:22:58		106:38:08	232:18:48	147:14:38
150	75:35:20	0:03:36	18:17:46	104Change Request Participants Verification	0:00:00		0:00:00	18:17:46	18:21:22
151	459:16:05	0:45:18	177:17:04	104Review (Participants)	285:28:53	3:55:03	119:28:12	343:17:45	178:02:23
153	454:56:12	1:36:10	104:00:27	104Review (Participants)	127:31:36	13:58:30	45:52:55	185:39:08	105:36:37
154	403:57:03	1:05:25	157:57:18	104Review (Participants)	332:48:48	70:54:09	110:14:17	380:31:49	159:02:44
155	401:45:51	0:20:04	155:59:16	104Review (Participants)	332:43:25	0:07:48	110:13:50	378:28:51	156:19:20
157	383:47:36	5:37:30	146:25:34	104Review (Participants)	305:32:09	30:35:34	113:32:02	338:25:41	152:03:04
159	505:03:23	47:45:58	98:41:54	104Review (Participants)	232:25:36	0:12:15	73:55:20	257:12:10	146:27:52
160	433:35:40	139:07:55	143:19:33	104Review (Participants)	306:23:45	70:00:36	110:14:49	339:28:29	282:27:28
161	361:46:56	9:10:28	132:32:29	104Approve (Engineer)	158:39:41		28:16:31	262:55:39	141:42:57
164	355:16:31	3:48:17	125:14:52	104Approve (Approver)	199:17:06		76:48:28	247:43:29	129:03:09
166	351:09:01	0:17:16	135:18:29	104Approver (Manager)	162:42:30		42:21:39	255:39:20	135:35:44
167	outlier			104Approved Close Out					
168	351:06:12	0:23:03	101:02:55	105Change Request Draft	166:39:52		28:24:04	239:18:43	101:25:58
169	382:12:11	30:45:31	116:08:29	105Verify Details	168:27:15		59:32:08	225:03:36	146:54:00
170	329:47:34	0:24:34	111:57:55	105Change Request Participants Verification	199:28:06		55:48:20	255:37:41	112:22:29
173	outlier			105Review (Engineer)					
174	190:42:37	4:03:07	56:35:59	105Approve (Approver)	72:50:20		20:27:03	108:59:16	60:39:06
176	358:50:52	29:17:56	103:45:50	105Approved Close Out	108:21:08		67:11:29	144:55:29	133:03:46

177	outlier			106Verify Details					
178	504:32:53	43:46:50	110:10:55	106Change Request Participants Verification	83:13:54		16:58:18	176:26:30	153:57:45
179	453:19:31	4:58:59	122:24:09	106Review (Engineer)	80:18:06		16:59:58	185:42:17	127:23:07
184	177:12:23	0:42:05	63:14:48	106Approve (Approver)	44:00:17		17:41:50	89:33:15	63:56:53
185	outlier			106Review (Engineer)					
186	745:40:53	70:52:14	136:17:16	106Approve (Approver)	74:12:16		19:11:11	191:18:22	207:09:31
188	380:09:11	9:29:36	85:11:43	106Approved Close Out	173:13:30		35:02:27	223:22:46	94:41:20
189	outlier			107Verify Details					
190	191:05:25	0:06:41	53:28:44	107Change Request Participants Verification	0:00:00		0:00:00	53:28:44	53:35:25
191	506:13:54	1:24:31	148:47:28	107Approve (Site Construction Manager)	167:36:05		30:58:01	285:25:32	150:11:59
192	357:52:32	1:21:14	87:11:19	107Approve (Assistant Construction Manager)	43:54:03		19:16:01	111:49:20	88:32:33
193	357:35:04	13:26:33	86:03:57	107Review (Engineer)	56:06:12		19:19:23	122:50:47	99:30:30
194	505:34:34	13:09:27	138:45:09	107Change Request Participants Verification	56:29:50		19:26:26	175:48:33	151:54:36
197	186:59:13	22:53:45	45:37:07	107Review (Participants)	99:22:09	117:17:25	28:15:28	116:43:48	68:30:52
205	166:49:35	1:44:04	44:02:10	107Review (Participants)	41:03:53	6:42:38	17:59:56	67:06:07	45:46:13
206	289:14:04	6:13:03	58:45:39	107Review (Participants)	74:19:21	23:15:54	16:24:47	116:40:14	64:58:42
207	outlier			107Review (Participants)		7:15:41			
208	641:08:46	51:25:54	149:49:18	107Review (Participants)	16:39:27	7:07:02	4:49:11	161:39:34	201:15:12
212	outlier			107Review (Participants)		10:37:21			
213	outlier			107Review (Participants)		10:22:09			
215	outlier			107Review (Participants)		63:30:56			
216	382:43:11	39:43:21	77:34:11	107Review (Participants)	31:05:00	3:50:39	21:08:40	87:30:32	117:17:33
217	outlier			107Review (Participants)		1:27:36			
218	449:43:30	3:04:38	113:11:24	107Approve (Engineer) Warning	71:34:46		23:03:13	161:42:58	116:16:02
219	354:59:56	7:49:07	82:09:21	107Approved Close Out	97:36:38		23:27:12	156:18:47	89:58:28
220	outlier			108Verify Details					
221	159:27:53	8:35:28	47:44:58	108Change Request Participants Verification	7:16:07		5:54:52	49:06:12	56:20:26
222	266:03:48	26:28:42	58:24:20	108Approve (Site Construction Manager)	95:55:29		35:32:12	118:47:37	84:53:02
223	434:40:42	51:35:26	98:49:23	108Approve (Assistant Construction Manager)	144:06:21		31:10:58	211:44:47	150:24:49
225	1009:55:23	239:25:26	71:32:08	108Review (Engineer)	0:00:00		0:00:00	71:32:08	310:57:34
227	261:05:43	8:52:04	69:17:38	108Change Request Participants Verification	27:03:23		11:25:27	84:55:33	78:09:42

229	405:46:20	7:44:17	104:00:28	108Review (Participants)	121:21:43	6:26:40	28:05:36	197:16:35	111:44:45
230	405:38:40	0:43:45	104:37:43	108Review (Participants)	124:59:16	3:56:28	28:04:57	201:32:01	105:21:28
232	217:47:51	0:31:49	48:38:07	108Review (Participants)	181:21:26	7:06:22	34:59:32	195:00:00	49:09:56
236	362:07:37	0:28:36	74:26:06	108Review (Participants)	59:52:26	7:02:53	16:54:04	117:24:29	74:54:42
241	69:34:47	11:13:54	22:20:32	108Review (Participants)	0:00:00	10:34:02	0:00:00	22:20:32	33:34:26
242	188:47:38	3:35:01	48:10:05	108Review (Participants)	14:14:57	10:32:20	5:54:36	56:30:26	51:45:06
243	69:11:34	14:29:19	18:41:41	108Review (Participants)	0:00:00	63:37:05	0:00:00	18:41:41	33:11:01
248	119:42:21	12:34:21	16:49:02	108Review (Participants)	10:01:45	0:26:33	8:08:46	18:42:01	29:23:23
249	209:44:47	12:14:32	33:25:25	108Approve (Engineer)	0:00:00		0:00:00	33:25:25	45:39:58
250	284:11:20	15:00:41	62:39:57	108Approver (Manager)	27:01:13		10:19:27	79:21:43	77:40:38
253	310:15:56	1:53:01	82:15:26	108Approver (Manager)	35:26:48		11:01:25	106:40:49	84:08:27
255	310:30:50	1:22:52	89:02:01	108Approved Close Out	63:32:21		17:31:47	135:02:35	90:24:53
271	119:02:48	0:31:05	34:38:05	112Verify Details	25:30:25		14:19:30	45:49:00	35:09:11
272	outlier			112Change Request Participants Verification					
273	outlier			112Approve (Site Construction Manager)					
274	665:04:49	134:16:01	98:52:35	112Approve (Site Construction Manager)	62:19:40		54:30:51	106:41:24	233:08:36
275	164:34:22	2:31:48	38:23:25	112Approve (Assistant Construction Manager)	50:49:50		17:31:00	71:42:16	40:55:13
277	1348:53:34	3:51:27	481:24:19	112Rejected Close Out	485:36:26		416:19:33	550:41:11	485:15:46
281	642:05:19	7:06:50	218:22:30	115Verify Details	87:11:32		51:08:20	254:25:42	225:29:20
282	71:46:01	11:48:01	11:57:26	115Change Request Participants Verification	0:00:00		0:00:00	11:57:26	23:45:27
284	211:46:51	0:22:38	57:48:33	115Approve (Site Construction Manager)	22:23:06		8:37:58	71:33:40	58:11:11
286	190:14:17	0:51:24	30:29:57	115Approve (Site Construction Manager)	33:55:34		10:06:47	54:18:44	31:21:21
287	189:42:20	0:34:51	30:29:45	115Approve (Assistant Construction Manager)	34:06:54		10:08:12	54:28:27	31:04:35
289	77:05:52	0:25:41	13:45:16	115Review (Engineer)	34:57:03		11:30:10	37:12:08	14:10:57
290	520:15:34	110:24:51	42:17:22	115Change Request Participants Verification	15:03:57		12:40:51	44:40:28	152:42:13
291	161:06:53	3:25:37	45:52:07	115Review (Participants)	43:39:13	0:22:35	14:56:11	74:35:08	49:17:44
293	outlier			115Review (Participants)	0:00:00	17:04:43			
295	837:44:59	173:08:31	93:29:37	115Review (Participants)	55:43:25	124:24:46	27:59:37	121:13:24	266:38:08
296	outlier			115Review (Participants)		121:06:34			
298	378:22:24	26:26:26	90:50:26	115Review (Participants)	13:39:51	35:30:18	4:55:49	99:34:28	117:16:52
299	314:32:26	0:40:22	89:15:32	115Review (Participants)	8:50:40	4:37:32	4:55:29	93:10:42	89:55:54

300				115Review (Participants)	0:00:00	98:45:56			
302	484:06:55	1:06:05	143:45:46	115Review (Participants)	64:24:08	7:15:57	54:57:36	153:12:18	144:51:52
303	471:16:12	3:14:18	105:44:10	115Approve (Engineer)	88:23:15		69:57:23	124:10:03	108:58:28
304	303:47:20	0:53:41	54:06:01	115Approved Close Out	50:12:24		13:57:25	90:21:00	54:59:42
306	289:34:23	0:20:41	75:39:33	117Verify Details	14:21:21		4:59:31	85:01:24	76:00:14
310	98:44:56	8:40:29	9:07:28	117Change Request Participants Verification	4:36:57		3:23:50	10:20:36	17:47:57
311	279:20:26	14:23:18	58:13:17	117Approve (Site Construction Manager)	8:06:06		5:13:47	61:05:36	72:36:35
Average									**118:09:38**

Workflow Implementation 4									
WF_ID	Instance Duration	Instance Effective Duration	Instance Waiting Duration	WF_ID & Activity Display Name	sum of review waits	Review times	max review time	total waits	Modified Instance Duration
312	232:41:16	9:17:08	37:58:07	312Verify Details	52:20:20		19:30:00	70:48:27	47:15:16
314	407:25:10	13:54:10	115:47:33	312Rework	66:49:38		46:08:28	136:28:44	129:41:43
315	401:21:45	4:33:31	107:18:21	312Verify Details	66:48:30		46:05:35	128:01:17	111:51:53
319	352:45:59	0:40:27	110:56:53	312Change Request Participants Verification	79:58:58		58:48:15	132:07:36	111:37:20
320	353:03:32	0:41:07	111:40:13	312Review (Engineer)	141:19:15		69:55:40	183:03:47	112:21:19
321	352:04:25	11:19:59	99:39:07	312Change Request Participants Verification	69:13:25		48:01:26	120:51:06	110:59:06
322	350:41:00	4:07:24	73:41:42	312Review (Participants)	56:10:30	19:30:00	46:55:39	82:56:32	77:49:05
323	350:17:14	4:53:24	84:06:36	312Review (Participants)	66:46:46	11:44:05	48:35:00	102:18:23	89:00:01
329	321:51:35	3:05:07	103:20:03	312Review (Participants)	87:31:53	0:55:49	55:00:12	135:51:44	106:25:10
330	309:58:18	2:06:28	79:18:42	312Review (Participants) Warning	70:32:08	5:26:08	31:22:48	118:28:02	81:25:11
331	outlier			312Review (Participants) Warning		5:27:01			
332	outlier			312Review (Participants) Warning		9:17:16			
333	483:43:25	117:27:28	88:57:57	312Approve (Engineer)	100:50:31		55:11:53	134:36:35	206:25:25
334	308:57:22	2:45:20	83:16:25	312Approve (Approver)	71:39:49		30:55:38	124:00:37	86:01:45
335	317:55:02	2:10:12	88:20:08	312Approved Close Out	70:34:12		31:22:47	127:31:32	90:30:20
336	1038:00:39	83:30:37	232:39:27	314Verify Details	266:46:04		107:55:55	391:29:36	316:10:04
338	383:49:15	19:43:13	74:15:56	314Change Request Participants Verification	153:08:33		38:44:57	188:39:32	93:59:10
339	307:14:27	29:59:59	85:15:13	314Approve (Site Construction Manager) Warning	82:37:39		60:15:30	107:37:22	115:15:13
341	296:35:25	2:18:45	82:22:39	314Approve (Assistant Construction Manager)	55:01:29		30:54:55	106:29:14	84:41:24
346	94:03:17	1:44:32	20:16:40	314Review (Engineer)	0:00:00		0:00:00	20:16:40	22:01:12

347	552:20:42	71:37:58	125:48:04	314Change Request Participants Verification	87:12:06		37:15:01	175:45:09	197:26:02
348	outlier			314Review (Participants)		0:22:03			
351	288:00:48	6:50:54	68:30:04	314Review (Participants) Warning	127:46:37	6:27:05	27:44:37	168:32:04	75:20:58
352	285:32:45	15:06:15	55:43:03	314Review (Participants) Warning	110:17:35	6:27:55	36:31:18	129:29:19	70:49:18
353	267:47:10	48:34:08	69:20:58	314Review (Participants) Warning	65:24:34	2:20:02	21:55:37	112:49:56	117:55:06
354	265:54:40	9:37:59	60:03:15	314Review (Participants) Warning	117:38:36	46:08:28	25:49:03	151:52:48	69:41:14
361	352:47:30	28:35:33	101:47:21	314Review (Participants) Warning	116:55:31	5:04:06	71:08:41	147:34:11	130:22:54
362	664:57:00	119:30:08	121:07:12	314Approve (Engineer)	112:23:05		57:40:27	175:49:49	240:37:20
363	236:42:19	11:56:17	96:56:56	314Approved Close Out	80:12:48		36:02:54	141:06:51	108:53:13
364	664:55:07	115:11:59	128:37:14	315Verify Details	110:09:32		57:41:43	181:05:03	243:49:13
365	outlier			315Change Request Participants Verification					
367	357:53:50	4:47:20	90:59:01	315Approve (Site Construction Manager) Warning	72:30:44		25:26:23	138:03:22	95:46:21
369	379:51:35	23:14:35	111:15:20	315Approve (Assistant Construction Manager)	70:37:35		37:17:59	144:34:57	134:29:55
370	186:04:25	0:07:57	65:55:30	315Review (Engineer)	0:00:00		0:00:00	65:55:30	66:03:27
371	185:28:41	5:05:14	60:22:24	315Change Request Participants Verification	0:00:00		0:00:00	60:22:24	65:27:37
372	474:45:39	1:21:11	144:02:26	315Review (Participants)	199:25:58	0:16:04	81:42:59	261:45:25	145:23:37
375	333:39:29	1:46:03	103:56:17	315Review (Participants) Warning	63:01:26	6:26:09	36:11:00	130:46:43	105:42:20
376	outlier			315Review (Participants) Warning		6:27:01			
381	308:14:50	0:44:05	109:31:00	315Review (Participants) Warning	70:11:52	2:25:57	37:19:39	142:23:14	110:15:06
382	740:13:36	46:54:37	166:23:22	315Review (Participants) Warning	339:45:22	46:05:35	114:50:09	391:18:35	213:18:00
384	841:38:55	173:56:31	109:34:13	315Review (Participants) Warning	131:05:02	5:07:44	62:35:43	178:03:32	283:30:44
386	597:48:22	40:14:11	183:55:26	315Approve (Engineer)	205:14:56		107:38:03	281:32:19	224:09:37
388	146:47:11	0:56:58	63:52:22	315Approved Close Out	39:54:25		26:58:10	76:48:37	64:49:21
389	145:59:21	0:27:15	63:25:11	319Verify Details	39:21:11		26:58:33	75:47:49	63:52:26
391	384:47:03	5:03:00	97:29:47	319Change Request Participants Verification	187:18:41		57:44:44	227:03:45	102:32:48
393	142:31:41	1:19:49	69:40:15	319Approve (Site Construction Manager) Warning	77:57:38		35:33:55	112:03:59	71:00:04
394	571:36:13	4:32:45	178:46:07	319Approve (Assistant Construction Manager)	237:53:56		119:10:22	297:29:41	183:18:52
395	311:37:02	3:33:01	85:24:23	319Review (Engineer)	144:52:10		56:45:53	173:30:41	88:57:24
396	573:30:26	1:07:14	189:43:43	319Change Request Participants Verification	178:36:37		119:09:06	249:11:14	190:50:57
397	571:20:24	63:29:53	119:35:35	319Review (Participants) Warning	180:46:02	6:25:11	62:45:09	237:36:28	183:05:27
398	557:52:43	1:36:40	168:58:59	319Review (Participants) Warning	298:49:06	6:24:30	119:17:02	348:31:03	170:35:40
399	555:48:38	21:28:26	166:36:56	319Review (Participants) Warning	193:21:01	2:29:35	107:48:07	252:09:49	188:05:22
400	546:55:26	0:54:23	169:31:32	319Review (Participants) Warning	256:42:21	58:48:15	107:42:32	318:31:21	170:25:55
402	529:08:41	1:40:24	159:59:53	319Review (Participants) Warning	182:18:28	5:16:27	107:24:26	234:53:55	161:40:16
403	1368:56:56	322:38:30	143:38:26	319Review (Participants) Warning	187:18:19	0:35:00	78:22:23	252:34:22	466:16:55
Average									135:57:41

Workflow Implementation 5									
WF_ID	Instance Duration	Instance Effective Duration	Instance Waiting Duration	WF_ID & Activity Display Name	sum of review waits	Review times	max review time	total waits	Modified Instance Duration
409	648:04:54	13:30:34	172:36:30	406Change Request Participants Verification	222:25:11		92:37:17	302:24:24	186:07:05
410	499:00:03	3:13:51	156:12:19	406Approve (Site Construction Manager) Warning	255:54:28		108:03:01	304:03:47	159:26:10
413	outlier			406Approve (Assistant Construction Manager) Warn					
415	471:48:34	2:42:58	143:28:32	406Review (Engineer)	160:17:43		105:56:31	197:49:43	146:11:30
416	620:04:45	0:30:44	172:39:02	406Change Request Participants Verification	155:35:16		76:21:42	251:52:36	173:09:46
417	931:31:55	24:20:54	310:07:12	406Review (Participants)	177:25:48	27:23:02	87:51:55	399:41:05	334:28:06
419	475:00:58	31:06:15	114:46:31	406Review (Participants)	111:50:29	0:28:15	75:25:56	151:11:05	145:52:46
420	outlier			406Review (Participants)		0:40:52			
421	596:48:58	8:44:44	157:54:46	406Review (Participants) Warning	262:22:34	18:57:14	75:10:29	345:06:52	166:39:30
423	427:51:07	73:26:44	91:41:00	406Review (Participants) Warning	21:59:37	62:50:41	12:43:27	100:57:10	165:07:44
424	593:28:10	18:01:34	167:29:41	406Review (Participants) Warning	263:27:52	1:43:18	75:27:54	355:29:40	185:31:15
425	426:14:48	8:51:00	83:40:30	406Review (Participants) Warning	223:07:45	56:20:29	70:39:05	236:09:10	92:31:29
426	568:45:31	3:48:01	143:10:55	406Approve (Engineer)	138:33:16		60:20:08	221:24:04	146:58:56
427	573:35:53	5:32:48	140:05:41	406Rejected Close Out	175:41:58		84:18:38	231:29:00	145:38:29
428	424:03:22	5:45:20	107:25:38	409Change Request Draft	159:10:21		76:20:59	190:15:00	113:10:58
429	533:07:15	3:15:33	135:40:52	409Verify Details	151:41:13		66:46:36	220:35:28	138:56:25
430	509:23:05	40:50:54	108:12:38	409Change Request Participants Verification	166:07:02		60:22:21	213:57:18	149:03:31
435	232:34:18	33:56:36	27:29:20	409Review (Engineer) Warning	0:00:00		0:00:00	27:29:20	61:25:56
Average									156:55:59

Workflow Implementation 6										
WF_ID	Instance Duration	Instance Effective Duration	Instance Waiting Duration	WF_ID & Activity Display Name	sum of review waits	Review times	max review time	total waits	Modified Instance Duration
437	19:06:23	0:58:54	6:06:48	436Change Request Participants Verification	0:00:00		0:00:00	6:06:48	7:05:42
440	478:10:47	70:57:58	144:33:06	436Review (Engineer)	250:10:24		75:07:03	319:36:27	215:31:04
445	453:21:58	1:58:57	66:45:06	436Change Request Participants Verification	154:56:50		48:25:27	173:16:29	68:44:03
446	671:10:38	7:41:27	259:04:00	436Review (Participants)	138:33:59	11:40:02	75:59:00	321:38:58	266:45:26
447	712:25:07	14:25:29	269:01:57	436Review (Participants)	106:53:58	1:38:36	77:11:24	298:44:31	283:27:26
449	471:46:22	61:40:41	93:30:01	436Review (Participants) Warning	211:12:22	19:54:58	75:02:49	229:39:35	155:10:42
451	1129:12:43	25:40:27	311:25:27	436Review (Participants) Warning	138:42:52	9:18:50	77:25:20	372:42:59	337:05:54
453	1611:07:17	290:32:33	248:48:06	436Review (Participants) Warning	149:58:14	70:04:35	89:33:19	309:13:01	539:20:38
458	762:58:14	28:28:55	235:14:28	436Review (Participants) Warning	178:41:33	15:35:54	88:59:44	324:56:17	263:43:23
461	265:45:33	2:04:02	115:31:36	436Review (Participants) Warning	0:00:00	71:59:34	0:00:00	115:31:36	117:35:38
463	692:40:47	22:21:18	231:30:42	436Approve (Engineer)	110:58:59		89:32:26	252:57:15	253:52:00
464	620:33:14	4:43:37	206:11:24	436Approve (Approver)	95:34:13		69:35:12	232:10:25	210:55:01
465	692:17:36	4:00:09	227:16:32	436Approved Close Out	177:33:01		88:56:02	315:53:31	231:16:42
467	458:57:16	2:18:57	194:23:38	437Verify Details	127:24:46		47:22:16	274:26:08	196:42:36
469	457:41:40	17:15:04	182:35:55	437Change Request Participants Verification	115:46:32		47:02:45	251:19:43	199:50:59
470	236:14:30	0:19:10	126:07:21	437Review (Engineer)	0:00:00		0:00:00	126:07:21	126:26:31
475	573:03:26	2:34:33	216:03:14	437Approve (Approver)	140:53:20		75:48:21	281:08:13	218:37:46
476	686:13:13	29:49:10	211:48:05	437Approved Close Out	118:38:04		81:49:52	248:36:17	241:37:15
478	686:03:15	10:11:39	231:14:35	440Verify Details	138:42:09		101:31:38	268:25:06	241:26:15
479	570:43:30	6:24:41	178:47:04	440Change Request Participants Verification	64:27:42		36:56:36	206:18:11	185:11:46

488	216:26:42	1:46:40	121:30:47	440Review (Engineer)	0:00:00		0:00:00	121:30:47	123:17:28
489	215:59:08	3:22:11	120:01:21	440Change Request Participants Verification	0:00:00		0:00:00	120:01:21	123:23:32
490	339:55:32	0:32:29	137:21:46	440Review (Participants) Warning	0:00:00	75:07:03	0:00:00	137:21:46	137:54:15
494	188:59:59	4:15:30	104:04:54	440Review (Participants) Warning	0:00:00	52:57:44	0:00:00	104:04:54	108:20:24
495	336:39:26	8:08:37	82:12:43	440Review (Participants) Warning	140:55:07	3:41:18	77:40:29	145:27:21	90:21:20
496	337:09:39	8:33:20	81:59:55	440Review (Participants) Warning	127:08:41	51:35:45	71:24:47	137:43:48	90:33:15
499	331:32:13	6:42:08	68:33:39	440Review (Participants) Warning	0:00:00	6:21:11	0:00:00	68:33:39	75:15:47
502	983:07:59	190:46:55	134:44:21	440Review (Participants) Warning	80:08:30	60:27:22	35:24:55	179:27:56	325:31:16
503	1986:16:31	1:03:13	685:22:17	440Approve (Engineer)	197:17:52		51:40:09	831:00:00	686:25:30
507	367:47:21	60:16:37	55:27:38	440Approve (Approver)	81:27:32		21:16:28	115:38:42	115:44:15
508	597:03:58	32:34:08	148:17:52	440Rejected Close Out	199:10:21		89:29:34	257:58:38	180:52:00
512	808:41:20	95:25:43	135:59:05	445Verify Details	208:09:51		116:53:14	227:15:41	231:24:48
513	954:08:06	152:32:50	145:05:24	445Rework	202:30:53		89:11:50	258:24:27	297:38:14
516	518:19:25	0:40:23	154:04:27	445Verify Details	108:22:25		47:19:51	215:07:00	154:44:49
518	1100:04:38	108:26:04	232:55:33	445Rework	200:20:30		112:01:34	321:14:29	341:21:37
521	451:31:11	71:14:48	56:57:06	445Verify Details	101:56:46		30:22:14	128:31:37	128:11:53
522	312:11:03	1:06:18	71:59:07	445Change Request Participants Verification	66:13:58		18:31:56	119:41:09	73:05:26
524	427:47:06	12:56:07	97:40:04	445Approve (Site Construction Manager)	120:18:27		76:59:44	140:58:47	110:36:11
525	408:00:56	1:12:24	101:56:37	445Approve (Assistant Construction Manager)	108:08:16		75:43:54	134:21:00	103:09:01
532	534:21:24	19:00:45	135:49:29	445Review (Engineer)	193:25:26		87:06:07	242:08:48	154:50:14
533	outlier			445Change Request Participants Verification					
541	377:29:27	5:01:09	103:41:53	445Review (Participants)	101:17:25	45:53:47	69:47:29	135:11:48	108:43:02
542	449:10:28	4:33:36	128:52:42	445Review (Participants)	195:11:03	45:06:22	89:34:39	234:29:06	133:26:18
543	811:27:01	14:18:13	249:13:48	445Review (Participants)	292:40:12	9:30:10	149:31:10	392:22:51	263:32:01
545	1052:50:46	350:56:45	14:36:35	445Review (Participants)	0:00:00	1:39:59	0:00:00	14:36:35	365:33:20
547	136:02:30	27:15:47	12:44:52	445Review (Participants) Warning	0:00:00	1:31:13	0:00:00	12:44:52	40:00:39
548	809:52:27	84:13:27	193:33:52	445Review (Participants) Warning	104:08:40	2:49:53	66:45:11	230:57:21	277:47:19
549	111:08:05	1:06:54	11:34:20	445Review (Participants) Warning	0:00:00	48:25:27	0:00:00	11:34:20	12:41:14
550	654:25:44	1:39:04	218:11:33	445Approve (Engineer)	165:11:54		85:24:31	297:58:56	219:50:37
551	817:25:00	32:26:57	219:35:09	445Approved Close Out	148:48:28		64:48:18	303:35:19	252:02:06
552	482:27:37	18:30:03	108:55:09	446Verify Details	124:56:20		66:37:06	167:14:23	127:25:12

554	639:04:51	186:59:17	58:12:48	446Rework	51:58:57		30:05:06	80:06:39	245:12:05
555	165:25:08	18:14:46	39:08:02	446Verify Details	0:00:00		0:00:00	39:08:02	57:22:48
559	722:04:43	19:28:31	238:17:24	446Change Request Participants Verification	294:15:09		149:34:07	382:58:26	257:45:55
560	721:21:22	22:10:41	238:07:03	446Approve (Site Construction Manager) Warning	281:46:44		149:08:15	370:45:32	260:17:44
561	55:34:27	0:54:00	18:38:09	446Approve (Site Construction Manager) Warning	0:00:00		0:00:00	18:38:09	19:32:08
562	716:48:59	79:21:29	242:56:34	446Approve (Assistant Construction Manager)	286:17:00		149:39:07	379:34:28	322:18:03
563	713:52:53	11:30:03	242:12:49	446Review (Engineer)	289:06:08		149:03:41	382:15:16	253:42:53
564	713:15:16	32:55:01	243:16:13	446Change Request Participants Verification	289:34:16		161:44:34	371:05:55	276:11:14
567	188:40:38	27:33:32	41:03:40	446Review (Participants)	5:44:11	13:13:29	5:44:11	41:03:40	68:37:12
568	188:39:58	3:10:56	65:24:53	446Review (Participants)	2:55:01	2:05:31	2:55:01	65:24:53	68:35:49
572	655:02:47	4:26:38	187:09:29	446Review (Participants)	161:10:08	0:08:54	64:30:56	283:48:41	191:36:07
573	681:23:24	3:47:31	201:57:06	446Review (Participants) Warning	153:58:12	3:09:27	64:41:50	291:13:28	205:44:37
574	287:40:20	2:01:40	76:08:51	446Review (Participants) Warning	0:00:00	17:55:52	0:00:00	76:08:51	78:10:31
575	320:30:49	3:37:57	95:22:28	446Review (Participants) Warning	0:00:00	18:07:53	0:00:00	95:22:28	99:00:25
576	334:53:28	18:57:17	79:29:10	446Review (Participants) Warning	0:00:00	7:53:53	0:00:00	79:29:10	98:26:26
578	474:10:00	155:10:29	18:17:43	446Review (Participants) Warning	0:00:00	75:59:00	0:00:00	18:17:43	173:28:12
582	653:56:25	1:58:25	187:13:34	446Approve (Engineer)	224:58:02		82:08:23	330:03:13	189:11:59
584	609:11:20	0:32:44	190:39:41	446Approved Close Out	156:39:02		64:36:25	282:42:19	191:12:25
585	608:59:24	1:17:05	190:00:15	447Verify Details	160:32:15		64:28:10	286:04:20	191:17:20
587	76:49:42	2:58:59	37:47:51	447Rework	0:00:00		0:00:00	37:47:51	40:46:49
595	187:04:13	5:28:11	40:56:06	447Verify Details	0:00:00		0:00:00	40:56:06	46:24:17
599	411:05:59	34:50:44	91:51:09	447Change Request Participants Verification	15:16:47		15:16:47	91:51:09	126:41:53
600	213:03:28	51:59:06	29:00:34	447Approve (Site Construction Manager) Warning	0:00:00		0:00:00	29:00:34	80:59:40
604	42:26:40	7:19:52	11:03:58	447Approve (Site Construction Manager) Warning	0:00:00		0:00:00	11:03:58	18:23:50
609	473:42:26	18:01:28	129:59:19	447Approve (Assistant Construction Manager)	183:40:58		64:54:33	248:45:43	148:00:47
610	528:06:45	47:23:01	136:23:53	447Review (Engineer)	172:28:33		95:32:26	213:20:00	183:46:54
613	outlier			447Change Request Participants Verification					
616	857:31:10	148:37:16	188:58:02	447Review (Participants)	150:01:31	2:09:47	64:51:44	274:07:49	337:35:18
617	160:45:39	2:16:59	47:54:51	447Review (Participants)	0:00:00	0:09:32	0:00:00	47:54:51	50:11:50
618	328:25:49	0:38:21	112:01:08	447Review (Participants) Warning	187:59:53	2:54:08	41:28:22	258:32:39	112:39:29
622	805:07:42	0:44:54	276:43:01	447Review (Participants) Warning	391:46:36	8:12:08	160:48:57	507:40:40	277:27:55

623	144:06:07	2:01:20	44:44:00	447Review (Participants) Warning	0:00:00	8:10:18	0:00:00	44:44:00	46:45:20
624	434:48:10	4:23:11	117:13:02	447Review (Participants) Warning	152:52:11	8:06:40	64:16:33	205:48:40	121:36:13
625	483:23:00	2:40:09	142:07:14	447Review (Participants) Warning	153:43:18	77:11:24	64:24:47	231:25:46	144:47:23
626	785:08:49	4:52:12	208:17:46	447Approve (Engineer)	242:58:29		78:15:24	373:00:51	213:09:59
627	981:11:46	31:08:15	288:22:59	447Approved Close Out	428:01:23		207:25:04	508:59:18	319:31:14
628	248:41:14	22:48:08	34:21:32	449Verify Details	0:00:22		0:00:22	34:21:32	57:09:40
629	411:47:31	1:36:27	107:50:07	449Change Request Participants Verification	153:54:51		64:22:37	197:22:21	109:26:34
632	242:27:04	10:31:49	43:16:05	449Review (Engineer)	0:00:00		0:00:00	43:16:05	53:47:54
633	614:25:28	73:22:46	155:26:11	449Change Request Participants Verification	164:23:49		64:46:38	255:03:22	228:48:57
636	224:22:14	13:43:04	42:13:08	449Review (Participants)	10:45:10	4:42:54	10:45:10	42:13:08	55:56:13
637	461:42:52	2:02:53	125:30:04	449Review (Participants) Warning	116:39:25	75:02:49	58:36:04	183:33:25	127:32:58
638	1536:07:08	303:26:14	187:57:54	449Review (Participants) Warning	71:00:49	9:26:25	29:18:38	229:40:04	491:24:08
639	222:39:44	11:16:03	42:59:09	449Review (Participants) Warning	10:46:59	52:00:24	10:46:59	42:59:09	54:15:12
643	197:57:58	12:04:45	35:14:07	449Review (Participants) Warning	0:00:00	6:23:34	0:00:00	35:14:07	47:18:52
648	691:29:40	0:53:51	186:58:55	449Review (Participants) Warning	206:47:15	60:29:42	111:45:26	282:00:44	187:52:47
649	691:21:28	0:53:35	187:26:58	449Review (Participants) Warning	206:21:49	3:06:35	111:48:09	282:00:38	188:20:33
651	407:05:51	0:20:03	128:33:54	449Approve (Engineer)	139:40:34		64:32:55	203:41:33	128:53:57
655	480:56:50	14:36:28	102:15:48	449Approve (Approver)	117:06:56		58:44:02	160:38:43	116:52:16
656	671:15:16	0:50:38	175:14:32	449Approved Close Out	183:20:19		87:49:01	270:45:49	176:05:10
658	718:44:33	0:35:44	244:48:05	451Verify Details	296:48:25		148:02:17	393:34:12	245:23:49
659	149:12:42	11:31:41	52:21:22	451Rework	0:00:00		0:00:00	52:21:22	63:53:04
660	148:49:55	10:40:07	42:08:15	451Verify Details	0:00:00		0:00:00	42:08:15	52:48:22
661	717:51:39	0:29:51	229:12:15	451Change Request Participants Verification	100:56:43		24:36:13	305:32:45	229:42:06
666	144:59:11	10:57:25	38:00:01	451Approve (Site Construction Manager) Warning	0:00:00		0:00:00	38:00:01	48:57:26
669	476:11:08	1:32:18	117:07:56	451Approve (Assistant Construction Manager) Warn	113:58:25		58:15:52	172:50:30	118:40:14
670	143:00:44	10:58:14	36:00:32	451Review (Engineer)	0:00:00		0:00:00	36:00:32	46:58:46
672	125:05:50	10:52:12	40:12:18	451Change Request Participants Verification	0:00:33		0:00:33	40:12:18	51:04:30
676	360:42:14	0:49:01	128:33:59	451Review (Participants)	131:27:18	6:15:18	70:27:25	189:33:52	129:23:00
680	687:51:23	7:00:41	221:33:24	451Review (Participants)	98:18:35	15:49:08	23:43:25	296:08:34	228:34:04
681	638:13:29	3:40:32	214:35:13	451Review (Participants) Warning	65:25:55	77:25:20	59:14:19	220:46:48	218:15:45
682	686:45:44	0:38:37	226:59:07	451Review (Participants) Warning	99:33:19	39:13:06	24:10:09	302:22:17	227:37:44

686	600:35:52	2:12:01	151:46:18	451Approve (Engineer)	120:03:35		53:57:41	217:52:12	153:58:19
687	365:14:47	29:11:04	103:22:29	451Approved Close Out	62:01:19		31:51:51	133:31:57	132:33:32
688	425:33:30	0:46:45	104:33:14	453Verify Details	154:32:06		37:46:10	221:19:09	105:19:59
694	937:01:11	171:04:28	157:23:50	453Rework	136:44:02		73:08:51	220:59:01	328:28:18
699	249:12:59	7:44:13	47:36:02	453Verify Details	71:00:02		22:07:52	96:28:12	55:20:15
700	504:23:48	9:46:45	135:21:49	453Change Request Participants Verification	0:00:00		0:00:00	135:21:49	145:08:34
701	20:07:30	5:19:54	2:47:32	453Approve (Site Construction Manager) Warning	0:16:30		0:12:06	2:51:56	8:07:25
703	403:23:01	0:48:11	107:39:35	453Approve (Assistant Construction Manager) Warn	20:47:43		20:14:55	108:12:23	108:27:46
704	571:11:40	150:18:00	30:33:36	453Review (Engineer)	0:00:00		0:00:00	30:33:36	180:51:36
705	307:06:40	0:08:59	84:51:36	453Change Request Participants Verification	0:00:00		0:00:00	84:51:36	85:00:35
706	663:35:57	87:46:00	109:36:40	453Review (Participants)	49:05:10	0:45:58	18:27:02	140:14:48	197:22:40
707	663:07:38	99:38:24	97:46:48	453Review (Participants)	38:49:15	2:00:08	16:16:24	120:19:39	197:25:12
708	648:37:54	85:05:03	112:09:36	453Review (Participants)	82:06:45	10:55:33	18:28:57	175:47:24	197:14:38
709	555:32:05	81:05:08	103:47:44	453Review (Participants) Warning	50:26:56	32:38:23	25:26:14	128:48:26	184:52:52
710	431:36:41	1:14:21	101:49:09	453Review (Participants) Warning	53:51:29	11:04:04	18:28:01	137:12:38	103:03:30
711	268:30:16	12:06:44	63:19:57	453Review (Participants) Warning	0:00:00	3:00:49	0:00:00	63:19:57	75:26:40
712	383:26:24	22:30:46	80:04:46	453Review (Participants) Warning	24:38:58	89:33:19	18:29:21	86:14:23	102:35:32
713	716:28:03	113:02:07	114:05:02	453Approve (Engineer)	101:23:36		51:49:55	163:38:43	227:07:09
714	742:51:27	135:59:39	118:03:09	453Approved Close Out	114:53:15		63:15:24	169:41:00	254:02:48
715	712:48:38	121:45:08	103:45:13	458Verify Details	112:39:41		63:10:58	153:13:56	225:30:20
716	353:27:37	8:30:26	87:22:39	458Rework	26:16:09		18:28:03	95:10:45	95:53:05
717	191:49:41	1:31:50	50:09:06	458Verify Details	87:17:05		22:10:49	115:15:22	51:40:56
720	841:35:33	153:31:32	116:14:02	458Change Request Participants Verification	0:00:00		0:00:00	116:14:02	269:45:35
722	377:55:21	0:40:59	101:06:56	458Approve (Site Construction Manager) Warning	49:50:41		18:29:05	132:28:32	101:47:55
723	380:00:36	12:04:06	89:43:32	458Approve (Site Construction Manager) Warning	42:28:35		18:50:23	113:21:44	101:47:38
724	600:28:46	31:39:12	162:30:51	458Approve (Assistant Construction Manager) Warn	62:52:26		18:27:11	206:56:06	194:10:03
725	235:35:33	72:30:58	25:04:35	458Review (Engineer)	77:27:23		23:39:01	78:52:57	97:35:32
728	351:02:32	0:16:24	80:46:22	458Change Request Participants Verification	56:26:46		18:29:42	118:43:27	81:02:46
730	547:12:12	33:50:42	134:38:21	458Review (Participants)	126:22:50	4:17:10	46:51:44	214:09:27	168:29:03
736	279:50:09	10:01:37	41:51:27	458Review (Participants)	46:11:56	0:53:07	19:39:11	68:24:11	51:53:04
743	80:09:52	0:23:50	24:16:39	458Review (Participants) Warning	2:34:43	88:59:44	2:10:27	24:40:55	24:40:29

744	79:04:08	0:11:23	24:00:47	458Review (Participants) Warning	2:32:38	11:52:38	2:09:47	24:23:38	24:12:10
745	209:02:44	1:36:04	56:24:08	458Review (Participants) Warning	65:09:30	2:53:52	20:53:51	100:39:47	58:00:12
747	142:39:46	1:39:35	45:53:40	458Review (Participants) Warning	55:23:06	69:45:02	19:38:42	81:38:04	47:33:15
749	141:24:29	7:07:23	38:41:36	458Approve (Engineer)	64:42:13		25:31:10	77:52:40	45:49:00
751	381:53:52	4:12:29	123:30:20	458Approved Close Out	71:52:17		41:06:48	154:15:50	127:42:49
752	1148:35:43	111:29:02	226:19:41	461Verify Details	292:56:11		62:16:13	456:59:39	337:48:43
759	160:37:37	0:20:28	23:26:40	461Change Request Participants Verification	23:55:22		12:26:29	34:55:33	23:47:08
761	337:36:22	52:08:14	84:34:34	461Approve (Site Construction Manager) Warning	83:20:17		41:11:54	126:42:57	136:42:48
Average									**160:24:41**

Workflow Implementation 7									
WF_ID	Instance Duration	Instance Effective Duration	Instance Waiting Duration	WF_ID & Activity Display Name	sum of review waits	Review times	max review time	total waits	Modified Instance Duration
771	312:54:00	1:47:36	83:37:31	768Rework	11:06:43		9:45:11	84:59:03	85:25:07
773	501:33:12	10:20:59	147:51:58	768Verify Details	92:41:44		54:21:00	186:12:42	158:12:57
774	496:17:45	7:40:00	156:07:30	768Change Request Participants Verification	189:15:58		78:22:43	267:00:45	163:47:30
775	112:08:26	0:27:46	39:40:22	768Approve (Site Construction Manager)	0:00:00		0:00:00	39:40:22	40:08:08
776	310:52:47	4:29:26	71:06:00	768Approve (Assistant Construction Manager)	14:59:35		10:18:39	75:46:55	75:35:26
777	306:11:36	0:36:42	75:31:06	768Review (Engineer)	10:13:21		10:13:21	75:31:06	76:07:49
778	305:37:27	2:27:25	82:31:38	768Change Request Participants Verification	11:24:43		10:11:26	83:44:54	84:59:02
786	257:36:52	0:19:11	72:47:26	768Review (Participants)	10:53:14	0:49:55	10:13:49	73:26:51	73:06:37
787	377:16:21	2:03:24	95:29:59	768Approve (Engineer)	109:27:47		62:20:49	142:36:57	97:33:23
788	839:46:19	234:57:18	74:38:54	768Approved Close Out	81:43:17		42:23:13	113:58:58	309:36:12
789	269:51:56	6:20:42	78:28:10	771Verify Details	107:57:26		39:31:33	146:54:03	84:48:52
798	621:30:01	4:50:20	191:02:30	771Rework	199:20:57		55:00:40	335:22:47	195:52:50
799	630:53:14	9:22:58	194:05:12	771Verify Details	232:21:01		71:15:13	355:11:00	203:28:10
802	887:51:42	283:15:36	154:24:52	771Change Request Participants Verification	101:42:14		42:19:44	213:47:21	437:40:28
804	519:37:40	2:53:38	161:01:24	771Approve (Site Construction Manager)	179:26:51		130:56:18	209:31:57	163:55:02
806	625:09:25	26:33:18	176:43:11	771Approve (Assistant Construction Manager) Warn	129:20:11		80:12:12	225:51:10	203:16:29
807	871:40:36	12:59:56	287:19:48	771Review (Engineer) Warning	195:20:30		143:55:39	338:44:38	300:19:44
808	577:40:57	0:14:43	199:34:40	771Change Request Participants Verification	196:19:50		54:58:05	340:56:25	199:49:23
809	341:44:40	5:22:46	103:04:52	771Review (Participants)	0:00:20	0:44:56	0:00:20	103:04:52	108:27:38
811	557:48:14	78:50:09	179:41:05	771Review (Participants)	211:02:21	0:36:36	55:01:19	335:42:07	258:31:13

819	820:26:17	4:50:20	266:46:57	771Review (Participants) Warning	191:37:18	9:45:11	56:00:09	402:24:06	271:37:17
820	572:41:49	18:26:52	182:12:59	771Approve (Engineer)	202:50:38		71:36:55	313:26:42	200:39:51
821	311:06:00	1:04:19	100:51:06	771Approved Close Out	1:38:25		1:38:25	100:51:06	101:55:26
825	527:18:00	3:37:22	170:32:47	773Verify Details	136:29:28		58:56:24	248:05:51	174:10:09
826	487:54:12	1:54:30	165:38:39	773Change Request Participants Verification	145:26:44		55:03:20	256:02:04	167:33:09
828	526:45:11	1:05:10	173:40:05	773Review (Engineer) Warning	157:39:36		56:19:38	275:00:04	174:45:15
832	499:05:48	0:52:33	156:53:04	773Change Request Participants Verification	183:56:21		71:16:07	269:33:18	157:45:37
840	161:05:45	0:37:14	15:49:12	773Review (Participants)	0:00:00	0:24:20	0:00:00	15:49:12	16:26:26
847	464:11:09	29:17:09	109:27:27	773Review (Participants) Warning	101:28:18	15:45:01	80:14:41	130:41:03	138:44:36
850	475:18:01	20:37:41	98:09:51	773Review (Participants) Warning	183:13:58	0:44:32	66:49:59	214:33:50	118:47:32
851	286:09:24	8:37:44	45:43:05	773Review (Participants) Warning	98:38:25	54:21:00	23:07:28	121:14:02	54:20:50
852	402:28:00	0:53:05	93:34:02	773Review (Participants) Warning	178:41:22	19:37:25	66:49:21	205:26:03	94:27:07
853	402:24:20	0:27:21	93:25:46	773Review (Participants) Warning	178:42:40	1:49:27	66:48:40	205:19:46	93:53:07
855	401:47:47	0:25:51	92:55:21	773Approve (Engineer)	178:50:12		66:50:32	204:55:01	93:21:12
856	400:23:14	13:05:33	91:31:54	773Approve (Approver)	201:27:13		66:47:30	226:11:37	104:37:27
857	719:39:41	151:49:05	81:32:05	773Approved Close Out	32:26:24		19:09:08	94:49:21	233:21:10
858	426:28:18	25:18:18	93:03:03	774Verify Details	158:47:49		63:04:15	188:46:38	118:21:21
859	625:58:41	116:31:07	111:49:55	774Change Request Participants Verification	203:10:55		56:21:06	258:39:45	228:21:03
861	358:09:38	18:45:53	107:09:35	774Review (Engineer)	130:06:46		56:18:42	180:57:39	125:55:27
863	357:37:23	3:55:18	99:11:05	774Change Request Participants Verification	201:40:24		56:16:55	244:34:35	103:06:23
864	314:24:30	6:47:11	96:43:04	774Review (Participants)	132:34:41	11:48:55	58:07:51	171:09:54	103:30:16
865	351:05:43	0:41:44	106:32:23	774Review (Participants) Warning	158:05:55	0:28:55	56:20:07	208:18:10	107:14:07
866	344:10:22	0:22:21	111:50:27	774Review (Participants) Warning	154:32:06	78:22:43	56:17:43	210:04:50	112:12:47
868	342:32:18	11:08:29	112:50:27	774Review (Participants) Warning	118:46:19	43:31:03	51:11:56	180:24:50	123:58:56
869	341:22:59	40:01:11	100:34:14	774Review (Participants) Warning	143:42:16	29:13:55	56:22:09	187:54:21	140:35:25
870	outlier			774Review (Participants) Warning		25:50:28			
872	331:56:45	3:03:38	96:54:15	774Approve (Engineer)	155:43:03		56:22:26	196:14:53	99:57:53
873	499:13:22	103:16:14	30:14:58	774Approve (Approver)	0:00:00		0:00:00	30:14:58	133:31:12
877	356:58:23	21:34:31	91:08:25	774Approved Close Out	227:54:51		56:25:02	262:38:14	112:42:57
883	724:41:39	79:01:41	154:37:05	775Verify Details	48:39:05		22:18:33	180:57:38	233:38:46
884	outlier			775Change Request Participants Verification					

885	outlier			775Review (Engineer)						
886	283:30:02	1:06:34	104:11:12	775Approve (Approver)	44:58:26		20:19:49	128:49:49	105:17:46
887	139:35:23	17:00:40	15:35:14	775Approved Close Out	0:00:00		0:00:00	15:35:14	32:35:54
888	507:07:11	7:36:10	179:00:33	776Verify Details	30:47:14		11:48:49	197:58:58	186:36:43
890	281:37:35	0:52:37	102:19:41	776Change Request Participants Verification	43:05:14		20:24:48	125:00:06	103:12:17
891	280:56:16	0:26:52	101:36:39	776Approve (Site Construction Manager) Warning	40:48:35		20:07:50	122:17:24	102:03:31
892	1792:41:29	382:56:47	271:03:41	776Approve (Assistant Construction Manager) Warn	33:59:15		19:38:23	285:24:33	654:00:28
893	334:55:44	26:11:20	112:26:27	776Review (Engineer)	40:03:37		12:14:28	140:15:36	138:37:47
896	213:13:44	11:23:11	73:09:31	776Change Request Participants Verification	47:37:34		20:29:04	100:18:02	84:32:42
897	outlier			776Review (Participants)		1:11:48			
898	434:48:42	116:57:01	96:06:29	776Review (Participants) Warning	76:30:26	3:29:08	27:18:37	145:18:17	213:03:30
899	210:13:00	0:55:22	50:51:06	776Review (Participants) Warning	33:20:52	10:18:39	11:21:58	72:49:59	51:46:29
902	160:03:08	0:48:35	29:03:22	776Approve (Engineer)	6:13:58		3:43:08	31:34:11	29:51:57
904	143:36:23	3:30:51	26:44:14	776Approved Close Out	25:37:01		8:38:09	43:43:06	30:15:05
910	481:51:46	54:09:07	112:46:26	777Verify Details	81:35:13		29:39:07	164:42:32	166:55:33
911	260:55:40	1:25:56	84:01:20	777Change Request Participants Verification	51:04:28		19:09:27	115:56:21	85:27:16
912	246:34:47	10:33:31	85:44:05	777Approve (Site Construction Manager) Warning	18:48:05		9:20:18	95:11:52	96:17:36
913	outlier			777Approve (Assistant Construction Manager) Warn					
914	outlier			777Review (Engineer)					
915	outlier			777Change Request Participants Verification					
916	169:58:34	0:31:41	47:42:51	777Review (Participants) Warning	20:42:44	10:13:21	15:19:42	53:05:53	48:14:32
917	169:41:10	0:28:02	36:29:10	777Approve (Engineer)	10:59:57		4:49:16	42:39:51	36:57:12
918	143:13:14	2:28:33	46:33:39	777Approved Close Out	17:39:22		14:43:40	49:29:21	49:02:12
919	140:48:29	2:09:29	45:56:18	778Change Request Draft	19:17:51		14:45:01	50:29:08	48:05:47
920	167:20:19	0:46:15	34:16:23	778Verify Details	8:42:59		4:46:43	38:12:39	35:02:38
923	282:38:33	49:30:15	45:59:19	778Rework	36:29:27		25:14:19	57:14:26	95:29:34
924	834:41:59	49:52:09	165:28:08	778Verify Details	169:16:34		68:38:20	266:06:21	215:20:17
926	239:18:04	0:57:21	79:21:59	778Change Request Participants Verification	7:54:43		4:58:01	82:18:41	80:19:20
927	334:34:43	1:09:07	105:03:22	778Approve (Site Construction Manager) Warning	80:30:23		63:33:12	122:00:33	106:12:29
928	217:27:11	0:33:41	68:35:10	778Approve (Assistant Construction Manager) Warn	36:04:09		25:08:39	79:30:40	69:08:50
931	187:47:02	0:20:38	52:57:41	778Review (Engineer)	7:50:05		4:32:11	56:15:34	53:18:19

932	431:15:08	17:03:51	116:22:31	778Change Request Participants Verification	38:20:03		15:40:38	139:01:56	133:26:22
933	431:08:12	0:34:25	131:30:57	778Review (Participants)	38:04:43	1:13:17	15:36:18	153:59:23	132:05:22
942	169:41:28	2:39:48	39:05:58	778Review (Participants) Warning	0:00:00	10:11:26	0:00:00	39:05:58	41:45:45
947	outlier			778Approve (Engineer)					
948	244:02:18	9:23:51	96:36:20	778Approved Close Out	9:42:23		8:27:41	97:51:02	106:00:11
951	189:09:39	1:20:41	61:30:03	786Verify Details	10:32:50		8:28:45	63:34:07	62:50:44
952	642:26:21	0:18:46	246:56:45	786Change Request Participants Verification	183:34:52		150:33:27	279:58:09	247:15:30
959	168:32:58	0:20:42	33:39:21	786Approve (Site Construction Manager) Warning	0:00:00		0:00:00	33:39:21	34:00:03
960	738:19:39	198:14:28	55:19:38	786Approve (Assistant Construction Manager) Warn	0:00:00		0:00:00	55:19:38	253:34:06
962	317:14:42	1:03:26	79:13:32	786Review (Engineer)	31:53:15		11:25:27	99:41:20	80:16:59
966	1337:57:02	163:06:54	275:51:13	786Change Request Participants Verification	50:58:10		42:45:31	284:03:53	438:58:07
967	833:26:16	108:21:28	173:39:24	786Review (Participants)	5:35:14	0:39:25	5:35:14	173:39:24	282:00:51
968	262:07:19	0:16:30	62:00:14	786Review (Participants) Warning	0:00:00	10:13:49	0:00:00	62:00:14	62:16:44
969	140:17:52	0:33:42	11:54:11	786Approve (Engineer)	0:00:00		0:00:00	11:54:11	12:27:53
971	223:21:03	2:37:19	75:58:10	786Approved Close Out	57:18:37		33:39:51	99:36:55	78:35:29
973	308:09:03	21:11:25	67:49:20	787Verify Details	40:51:20		22:17:24	86:23:16	89:00:45
974	217:40:27	0:44:42	80:00:30	787Change Request Participants Verification	32:06:59		31:32:51	80:34:37	80:45:12
975	471:18:49	104:03:46	64:44:35	787Approve (Site Construction Manager) Warning	57:07:34		33:35:59	88:16:09	168:48:20
976	99:54:02	0:28:39	35:24:58	787Approve (Assistant Construction Manager) Warn	17:48:04		11:40:54	41:32:08	35:53:37
977	789:37:19	176:19:51	86:15:49	787Review (Engineer)	145:09:56		47:32:29	183:53:16	262:35:40
981	115:03:16	12:42:08	30:29:16	787Change Request Participants Verification	7:17:16		6:03:32	31:43:01	43:11:24
982	68:04:48	1:12:51	18:54:07	787Review (Participants)	0:00:00	0:06:16	0:00:00	18:54:07	20:06:58
983	196:39:10	9:49:44	50:31:10	787Review (Participants)	10:52:37	1:02:29	5:41:34	55:42:13	60:20:54
984	362:25:12	35:06:36	85:33:19	787Review (Participants)	27:43:02	0:34:02	18:30:05	94:46:16	120:39:55
985	362:18:31	36:05:43	84:43:05	787Review (Participants) Warning	42:29:41	1:36:11	18:47:23	108:25:23	120:48:48
986	362:10:13	30:10:01	90:19:02	787Review (Participants) Warning	19:21:26	62:20:49	18:41:01	90:59:27	120:29:02
987	1558:07:19	123:11:22	426:25:58	787Review (Participants) Warning	22:43:44	34:00:16	14:23:24	434:46:18	549:37:20
988	234:20:02	15:08:21	75:25:13	787Review (Participants) Warning	53:44:42	9:47:44	37:24:26	91:45:30	90:33:34
989	192:06:42	0:32:48	55:20:44	787Approve (Engineer)	10:38:20		5:37:23	60:21:42	55:53:33
997	212:45:30	5:26:13	58:19:25	787Approved Close Out	86:21:32		35:31:40	109:09:16	63:45:38
998	123:05:43	2:46:27	41:40:00	788Verify Details	22:55:37		11:31:33	53:04:04	44:26:27

999	1484:28:40	129:15:29	379:57:26	788Change Request Participants Verification	196:01:23		189:35:28	386:23:21	509:12:55
1001	795:19:19	35:14:51	198:57:10	788Approve (Site Construction Manager)	107:53:04		41:47:45	265:02:28	234:12:01
1007	outlier			788Approve (Assistant Construction Manager)					
1008	331:40:52	43:17:57	53:28:45	788Review (Engineer)	65:05:27		27:28:08	91:06:05	96:46:42
1009	311:01:49	37:31:54	89:56:33	788Change Request Participants Verification	64:21:24		49:55:29	104:22:28	127:28:27
1012	1414:58:00	184:24:40	333:59:23	788Review (Participants)	32:16:17	20:21:20	20:16:54	345:58:46	518:24:03
1013	218:17:56	0:19:14	65:23:00	788Review (Participants)	18:54:04	0:02:20	18:26:59	65:50:05	65:42:14
1014	217:42:54	1:11:17	64:48:23	788Review (Participants)	27:55:49	5:35:26	18:41:39	74:02:33	65:59:40
1017	285:38:02	37:35:17	97:15:43	788Review (Participants)	72:01:18	2:02:44	42:45:10	126:31:51	134:50:59
1018	198:32:49	0:37:58	65:36:26	788Review (Participants) Warning	39:13:51	3:47:42	18:56:27	85:53:50	66:14:24
1019	198:19:34	0:37:41	65:25:09	788Review (Participants) Warning	26:00:57	42:23:13	18:54:50	72:31:16	66:02:50
1025	1749:53:59	136:07:47	443:23:37	788Review (Participants) Warning	99:37:35	7:30:33	95:55:33	447:05:39	579:31:24
1026	718:56:30	103:33:09	107:17:50	788Approve (Engineer)	0:00:00		0:00:00	107:17:50	210:50:59
1027	718:50:08	103:04:23	107:42:22	788Rejected Close Out	0:00:00		0:00:00	107:42:22	210:46:45
1028	718:40:20	121:39:18	87:41:03	789Verify Details	0:00:00		0:00:00	87:41:03	209:20:20
1029	outlier			789Change Request Participants Verification					
1031	256:17:53	0:39:53	80:32:37	789Approve (Site Construction Manager)	40:25:13		39:28:10	81:29:40	81:12:30
1032	169:30:52	41:50:53	54:28:19	789Approve (Assistant Construction Manager) Warn	36:03:28		29:02:06	61:29:41	96:19:12
1033	outlier			789Review (Engineer)					
1036	859:08:56	74:02:51	183:11:55	789Change Request Participants Verification	84:05:12		29:48:50	237:28:17	257:14:46
1037	1315:34:43	0:34:48	464:11:07	789Review (Participants)	278:28:59	1:10:41	177:37:58	565:02:08	464:45:56
1038	1302:11:21	7:22:29	501:16:16	789Review (Participants)	180:35:35	1:17:07	50:09:36	631:42:15	508:38:45
1044	1272:52:56	124:40:37	368:36:21	789Review (Participants) Warning	108:33:14	3:45:40	54:53:04	422:16:31	493:16:58
1045	339:50:20	7:42:03	104:59:15	789Review (Participants) Warning	106:36:29	39:31:33	54:26:01	157:09:43	112:41:18
1046	712:35:34	58:08:52	168:30:30	789Review (Participants) Warning	23:20:33	38:44:22	14:49:37	177:01:26	226:39:22
1047	1270:48:42	64:59:57	416:03:48	789Review (Participants) Warning	20:40:09	7:55:51	9:54:34	426:49:24	481:03:45
1048	596:11:36	0:36:23	183:31:49	789Review (Participants) Warning	107:20:12	15:32:12	53:46:55	237:05:06	184:08:12
1049	595:53:50	6:46:22	155:24:42	789Approve (Engineer)	36:09:22		18:34:18	172:59:46	162:11:04
1052	48:12:22	1:02:51	23:11:40	789Approver (Manager)	0:00:00		0:00:00	23:11:40	24:14:31
1053	outlier			789Approved Close Out					
1059	outlier			798Verify Details					

1060	outlier			798Change Request Participants Verification						
1061	outlier			798Approve (Site Construction Manager) Warning						
1062	outlier			798Approve (Assistant Construction Manager) Warn						
1063	1540:17:32	250:04:04	297:10:01	798Review (Engineer)	219:46:44		82:13:27	434:43:18	547:14:05
1064	outlier			798Change Request Participants Verification						
1066	505:27:57	2:13:26	151:40:54	798Review (Participants)	95:39:55	48:54:29	53:43:42	193:37:06	153:54:20
1067	550:34:49	49:38:20	114:24:29	798Review (Participants)	79:46:29	55:00:40	53:26:38	140:44:20	164:02:49
1071	1108:14:58	201:01:11	159:10:44	798Review (Participants)	65:22:20	2:44:33	27:17:28	197:15:36	360:11:55
Average										158:30:10

Workflow Implementation 8

WF_ID	Instance Duration	Instance Effective Duration	Instance Waiting Duration	WF_ID & Activity Display Name	sum of review waits	Review times	max review time	total waits	Modified Instance Duration
1073	1121:51:20	0:24:08	387:09:31	1072Change Request Participants Verification	165:18:04		143:34:07	408:53:28	387:33:38
1074	1101:26:38	0:25:10	381:08:27	1072Approve (Site Construction Manager)	0:00:00		0:00:00	381:08:27	381:33:37
1075	outlier			1072Approve (Assistant Construction Manager)					
1077	403:40:18	10:23:35	110:23:09	1072Review (Engineer)	103:12:49		41:56:13	171:39:45	120:46:44
1078	452:58:50	53:33:37	120:01:54	1072Change Request Participants Verification	195:37:35		65:59:30	249:39:59	173:35:31
1079	502:22:17	0:19:17	165:15:01	1072Review (Participants) Warning	55:38:12	54:02:40	17:53:01	203:00:12	165:34:19
1080	383:17:13	0:27:43	102:28:35	1072Review (Participants) Warning	31:12:50	14:08:46	17:57:44	115:43:41	102:56:18
1081	1056:59:39	136:02:44	274:06:25	1072Review (Participants) Warning	34:16:08	29:53:21	15:16:37	293:05:56	410:09:08
1082	382:50:53	0:19:06	102:15:34	1072Review (Participants) Warning	110:32:11	3:31:17	41:58:58	170:48:47	102:34:40
1084	381:59:47	0:27:34	116:40:15	1072Approve (Engineer)	19:02:32		8:00:31	127:42:15	117:07:49
1085	1052:05:38	165:59:05	179:40:45	1072Approved Close Out	41:22:23		17:17:49	203:45:19	345:39:50
1088	359:00:17	22:41:41	108:28:46	1073Change Request Draft	68:32:59		24:37:44	152:24:02	131:10:27
1089	355:57:45	10:39:43	101:54:24	1073Verify Details	55:32:21		17:54:02	139:32:44	112:34:07
1090	388:33:29	40:11:59	65:11:28	1073Rework	45:00:45		18:08:49	92:03:24	105:23:27
1092	381:41:07	35:02:17	104:04:47	1073Verify Details	103:17:53		41:57:51	165:24:49	139:07:05
1096	1002:34:41	220:10:26	120:40:53	1073Change Request Participants Verification	94:55:39		40:19:39	175:16:52	340:51:19
1098	406:17:25	0:40:11	140:41:02	1073Review (Engineer)	153:46:10		86:06:09	208:21:02	141:21:13
1101	956:37:31	191:28:30	146:51:42	1073Change Request Participants Verification	107:45:03		30:04:11	224:32:34	338:20:12
1102	200:15:29	11:48:10	73:08:35	1073Review (Participants) Warning	35:16:17	0:54:28	17:10:26	91:14:27	84:56:45
1103	168:24:12	3:05:39	69:21:00	1073Review (Participants) Warning	32:00:54	7:34:14	17:04:36	84:17:18	72:26:39
1104	618:19:07	0:14:05	167:07:52	1073Review (Participants) Warning	0:00:00	5:41:32	0:00:00	167:07:52	167:21:57
1105	outlier			1073Review (Participants) Warning		5:02:17			
1106	1276:25:31	193:12:46	247:25:11	1073Review (Participants) Warning	0:20:53	143:34:07	0:20:53	247:25:11	440:37:57
1107	770:45:54	128:43:15	132:16:32	1073Review (Participants) Warning	103:37:35	2:31:26	53:04:48	182:49:19	260:59:47
1108	1273:21:04	180:18:42	252:26:16	1073Approve (Engineer)	10:39:15		5:25:24	257:40:07	432:44:58
1109	594:42:08	6:45:08	188:31:09	1073Approve (Approver)	210:44:26		117:40:00	281:35:34	195:16:17
1111	152:48:10	3:57:02	57:36:59	1073Approved Close Out	55:34:20		17:35:50	95:35:29	61:34:01
1112	119:54:04	1:42:11	47:25:16	1074Change Request Draft	52:47:17		18:15:01	81:57:32	49:07:28
Average									205:18:40

Appendix K: Sensitivity Analysis Data

		Batch 1			Batch 5			Batch 15			Batch 30		
Res 100%	Rew R 5%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%
GEN One	Average Time in System	44.44	46.81	49.18	46.14	48.30	50.47	50.26	52.54	54.82	61.35	63.05	64.76
GEN Two	Average Time in System	48.92	50.60	52.29	51.27	52.85	54.43	54.22	55.96	57.71	62.87	64.73	66.60
GEN Three	Average Time in System	47.06	49.35	51.63	47.06	49.35	51.63	47.06	49.35	51.63	47.06	49.35	51.63
GEN One	Number Completed	66	68	69	64	66	68	60	62	63	53	55	57
GEN Two	Number Completed	64	67	69	63	65	67	61	63	65	55	57	59
GENThree	Number Completed	64	66	69	64	66	69	64	66	69	64	66	69

		Batch 1			Batch 5			Batch 15			Batch 30		
Res 100%	Rew R 15%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%
GEN One	Average Time in System	44.80	47.30	49.81	46.51	48.71	50.91	49.53	51.56	53.58	58.96	60.82	62.69246
GEN Two	Average Time in System	48.82	50.51	52.20	51.34	53.06	54.77	54.47	56.22	57.97	62.41	64.26	66.10
GEN Three	Average Time in System	47.06	49.35	51.63	47.06	49.35	51.63	47.06	49.35	51.63	47.06	49.35	51.63
GEN One	Number Completed	66	68	69	64	66	68	60	61	63	53	55	56
GEN Two	Number Completed	64	66	68	62	65	67	61	63	65	55	57	59
GENThree	Number Completed	64	66	69	64	66	69	64	66	69	64	66	69

		Batch 1			Batch 5			Batch 15			Batch 30		
Res 100%	Rew R 30%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%
GEN One	Average Time in System	45.24	47.59	49.93	46.77	49.11	51.45	50.26	52.36	54.47	55.17	57.31	59.44
GEN Two	Average Time in System	49.43	51.07	52.70	51.40	52.90	54.40	54.07	55.96	57.86	62.24	64.10	65.95
GEN Three	Average Time in System	47.05	49.35	51.64	47.05	49.35	51.64	47.05	49.35	51.64	47.05	49.35	51.64
GEN One	Number Completed	65	67	69	63	65	67	59	61	62	52	54	56
GEN Two	Number Completed	64	66	68	63	65	67	60	63	65	55	57	59
GENThree	Number Completed	64	66	69	64	66	69	64	66	69	64	66	69

Res 50%	Rew R 5%	Batch 1			Batch 5			Batch 15			Batch 30		
		-95%	Average	95%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%
GEN One	Average Time in System	50.25	54.97	59.70	53.35	57.06	60.77	58.34	61.35	64.37	65.86	69.23	72.60
GEN Two	Average Time in System	60.05	63.83	67.60	61.01	64.39	67.78	62.81	66.29	69.77	70.71	75.04	79.37
GEN Three	Average Time in System	64.12	67.69	71.26	62.68	66.02	69.36	62.30	65.92	69.54	62.52	66.66	70.81
GEN One	Number Completed	36	39	41	36	38	40	35	37	39	31	33	36
GEN Two	Number Completed	34	37	39	35	37	39	34	36	38	29	32	34
GENThree	Number Completed	28	30	32	27	30	32	28	30	32	27	29	31

Res 50%	Rew R 15%	Batch 1			Batch 5			Batch 15			Batch 30		
		-95%	Average	95%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%
GEN One	Average Time in System	56.03	58.72	61.41	56.91	60.75	64.58	63.88	66.95	70.01	69.04	72.55	76.06
GEN Two	Average Time in System	58.81	62.58	66.35	58.17	62.46	66.75	67.43	70.74	74.04	73.52	77.23	80.93
GEN Three	Average Time in System	60.60	64.17	67.75	61.55	65.42	69.28	63.79	67.81	71.84	64.03	67.33	70.64
GEN One	Number Completed	35	37	39	34	37	40	33	35	37	29	31	33
GEN Two	Number Completed	36	37	39	35	37	38	31	34	37	30	31	33
GENThree	Number Completed	28	31	33	27	30	32	27	29	31	27	29	31

Res 50%	Rew R 30%	Batch 1			Batch 5			Batch 15			Batch 30		
		-95%	Average	95%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%
GEN One	Average Time in System	57.21	59.73	62.26	57.30	60.27	63.23	63.00	66.20	69.40	69.46	73.14	76.83
GEN Two	Average Time in System	58.69	62.56	66.43	60.25	63.20	66.14	62.80	66.00	69.20	69.83	73.52	77.22
GEN Three	Average Time in System	62.69	65.85	69.02	64.25	67.86	71.48	61.72	65.83	69.93	63.56	66.90	70.24
GEN One	Number Completed	35	37	39	33	36	38	31	34	36	28	31	33
GEN Two	Number Completed	34	37	40	35	37	39	32	35	37	31	33	34
GENThree	Number Completed	28	31	34	28	30	33	29	31	33	28	30	33

Res 10%	Rew R 5%	Batch 1			Batch 5			Batch 15			Batch 30		
		-95%	Average	95%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%
GEN One	Average Time in System	33.60	48.09	62.59	40.82	52.00	63.18	48.32	64.30	80.28	57.62	69.97	82.32
GEN Two	Average Time in System	39.78	60.49	81.20	40.93	57.97	75.00	49.83	69.19	88.56	44.61	62.54	80.48
GEN Three	Average Time in System	28.38	40.56	52.74	37.52	53.53	69.55	26.31	39.83	53.36	29.83	42.46	55.08
GEN One	Number Completed	8	11	14	8	10	13	8	12	15	8	11	14
GEN Two	Number Completed	2	4	6	4	7	9	5	8	10	5	7	9
GENThree	Number Completed	3	4	6	4	5	7	3	5	6	3	5	7

Res 10%	Rew R 15%	Batch 1			Batch 5			Batch 15			Batch 30		
		-95%	Average	95%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%
GEN One	Average Time in System	36.90	50.20	63.50	52.66	65.14	77.63	32.12	50.94	69.75	43.30	62.08	80.86
GEN Two	Average Time in System	37.12	56.45	75.77	52.02	67.48	82.94	51.77	65.81	79.86	55.91	72.41	88.90
GEN Three	Average Time in System	36.98	51.41	65.84	55.56	69.80	84.04	34.41	47.41	60.40	31.21	44.88	58.54
GEN One	Number Completed	7	10	14	11	13	16	5	8	11	5	8	10
GEN Two	Number Completed	3	5	7	5	6	8	6	9	11	6	8	11
GENThree	Number Completed	4	6	8	4	6	7	3	5	7	3	4	5

Res 10%	Rew R 30%	Batch 1			Batch 5			Batch 15			Batch 30		
		-95%	Average	95%	-95%	Average	95%	-95%	Average	95%	-95%	Average	95%
GEN One	Average Time in System	38.53	52.08	65.63	38.95	52.32	65.69	43.48	61.35	79.22	37.94	54.73	71.52
GEN Two	Average Time in System	45.73	65.50	85.27	42.13	61.24	80.35	39.64	57.57	75.50	47.71	65.53	83.36
GEN Three	Average Time in System	35.96	48.13	60.31	47.14	64.14	81.14	32.65	45.39	58.14	27.90	42.29	56.68
GEN One	Number Completed	7	10	14	9	11	14	5	8	11	5	7	10
GEN Two	Number Completed	3	5	7	3	5	8	4	7	9	4	7	9
GENThree	Number Completed	4	6	7	5	6	8	3	5	7	3	4	5